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Coal Liquefaction and Health:

Elements of a Worker Health Surveillance Program

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Foreword

The rapid escalation of the cost of liquid fuels during the 1970's and the concerns felt about declining conventional petroleum reserves, were accompanied by an intensified world-wide interest in alternative sources of fuel and in particular, the search for improved processes to convert non-conventional fuels to new or synthetic liquids. In Canada this interest was translated into a desire to achieve self-sufficiency through the development of conversion technologies applicable to the very substantial heavy oil, tar sands and coal resources available for exploitation. An acceleration of research and development efforts in this direction was actively supported by both government and industry.

As a participant in the federal government's energy research and development program Health and Welfare Canada has been involved in an ongoing review and study of the potential impact of the new synthetic fuels on health. One special focus has been the study of the potential health effects of coal liquefaction processes and the development of guidelines and procedures for the protection of workers in Canadian coal liquefaction research and development establishments. Two reports were prepared and submitted for peer review. This report is an integrated version of the two earlier reports.

Coal liquefaction and coal liquefaction research in Canada and elsewhere is briefly reviewed in Chapter I. Chapter II deals with current safety and health concerns and Chapter III with environmental and industrial hygiene control measures. Medical aspects of health surveillance and the development of a record system and a Coal Liquefaction Worker Registry, are dealt with in Chapters IV and V respectively.

The proposed health surveillance system was designed having the health protection of coal liquefaction workers in mind. It could, however, be made equally applicable to other branches of the new synthetic fuels industry.

I Introduction

1. Historical Perspective

Interest in coal-derived liquids, based on by-product coking, began in both England and Germany[1,2] during the early part of the nineteenth century. However, it was not until the 1920's that coal liquefaction processes were introduced commercially.

Several processes were developed in Germany. The Winkler process was introduced in 1926 at a plant at Leuna for the gasification of brown coal. It was the first large-scale commercial use of the technology of fluidization, which later became widely used in the petroleum industry. Another approach to "oil from coal", the Bergius process, pioneered originally in 1913[3], involved the hydrogenation of coal under high temperature and pressure. It was further exploited during the 1930's and was very successful using bituminous coals. During World War II, Germany produced up to eighty-five percent (85%) of her motor and aviation fuels from coal. At the end of the war, however, all plants were closed and the only plants to survive were in East Germany.

In the post-war period, coal to gasoline and diesel fuel processes generally lost their economic efficiency due to the availability of cheaper crude oils. In the pre-1970 period the only commercial operations were to be found in South Africa.

It was not until after the oil crises of the 1970's that new pilot plants were constructed in Germany. Full scale commercial plants were also designed but have not yet been constructed[4,5].

In the United States, a demonstration plant was erected at Louisiana, Missouri, at the end of the War, with the use of some German equipment[3], and in 1952, the first large scale hydrogenation pilot plant began operating at Institute, West Virginia for the production of coal derived chemicals (it closed in 1959)[6]. Others were constructed and included the Solvent Refined Coal (SRC) process plant at Fort Lewis, Washington, the Hydrocarbon Research (H-coal) process pilot plant at Catlettsburg, Kentucky and the Exxon Donor Solvent (EDS) process pilot plant at Baytown, Texas[6,7].

Spurred on by the oil crisis, research activities reached a peak during the 1970's and construction of commercial scale plants were envisaged for the late 1980s. The current competitiveness of crude oil supplies delayed their development. It also resulted in the closure of pilot plants. Nevertheless, selected coal conversion (gasification) technologies were adapted for the production of energy on a local institution or industry basis[8,9,10].

Coal liquefaction research was also given priority in other countries such as Australia and Japan. In Japan the construction of a full scale commercial undertaking has been proposed for the early 1990's.

In Canada, coal conversion technologies were first explored in Alberta during the 1930's and the results of research related to the hydrogenation of Alberta coals were reported[11]. However, as elsewhere, it was not until the latter part of the 1970's that coal liquefaction research and development gained significantly increased momentum.

2. The Composition of Coal and the Nature of the Liquefaction Process

Chemically, coal is a complex heterogeneous mixture of inorganic and hydro-deficient organic matter[7]. The organic portion is composed largely of polycyclic aromatic structures held together by carbon and hetero-atom linkages. In addition to carbon and hydrogen, coal contains significant quantities of oxygen, nitrogen and sulphur and covalently bound metals. The inorganic portion of coal (ash), contains trace amounts of practically all the elements in the periodic table[12].

The structure, composition and age of coal vary from region to region and may affect the nature of the coal liquefaction process as well as the composition of the process products.

The main objective in coal liquefaction is to produce liquid hydrocarbons with a higher hydrogen-to-carbon ratio than the coal feedstock while at the same time reducing the sulphur, nitrogen and oxygen content, removing mineral matter and minimizing gas production[13].

Liquefaction of coal occurs under conditions of high temperatures and pressures and varying reactor exposure (transit) times. Bonds between the aromatic rings are broken producing smaller molecules. Breakages are accelerated by the presence of hydrogen or a hydrogen-containing donor solvent. The hetero-atoms, nitrogen, sulphur and oxygen, react to form ammonia, hydrogen sulphide, carbon monoxide, carbon dioxide and water. Numerous other compounds are formed during the various stages of the process. Prominent among these are the polycyclic aromatic hydrocarbons*.

* The terms PNAs and PAHs are often used interchangeably. Strictly, however, PNAs (polynuclear aromatic compounds) contain two or more fused aromatic rings. PAHs (polycyclic aromatic hydrocarbons) are PNAs restricted to having only carbon and hydrogen as constituent elements. PNAs may also include heterocyclic compounds containing oxygen, nitrogen, sulphur and other elements and substituted PAH compounds.

Process raw materials vary but may include, in addition to coal, start-up solvents (tetralin, anthracene oil, donor solvent) and hydro-treating catalysts. A spectrum of low-molecular weight end-products, including liquefied petroleum gases (LPGs) and light distillates, is produced; the proportions of these products vary with the process being used[2]. Heavier oil products, tar and char are also produced which, with subsequent liquefaction or hydrotreating, can be converted to lighter distillates or specified new liquid fuels.

3. Approaches to Coal Liquefaction

There are two basic approaches to coal liquefaction[13]: a degradation route and a synthesis route. The degradation route involves a partial breakdown of the complex coal structure into simpler molecules (direct liquefaction) and is further divided into processes which add hydrogen (direct hydro-liquefaction) and those that remove carbon (pyrolysis). In the synthesis route complete destruction of the coal structure is achieved to produce a synthesis gas - primarily a mixture of carbon monoxide and hydrogen - which is catalytically converted in a second step to liquid hydrocarbons (indirect liquefaction). A general outline of the coal liquefaction process is shown in Figure 1.

Direct liquefaction processes may be catalytic or non-catalytic (solvent extraction processes). An example of the non-catalytic process is the Solvent Refined Coal process (SRC I)[14,15]. Pulverized coal is mixed with a process-derived solvent in a slurry mix tank. The slurry is combined with hydrogen and pumped through a pre-heater, reactor and filter. A principle product of this process is the solvent-refined coal. Other examples of non-catalytic processes include the SRC-II, the Exxon Donor-Solvent (EDS) and the Consol Synthetic Fuel (CSF) processes. Hydrogen is used in the SRC and EDS processes but not in the CSF process. The products of these processes are primarily aromatic in nature. The naphtha portion can serve as gasoline precursors.

Catalytic liquefaction is exemplified by the H-Coal process which produces boiler fuels and a synthetic crude oil from high-sulphur coal in an ebulated-bed catalytic reactor[15]. Coal, slurried with a coal-derived recycle oil, is reacted at 412-468°C (800-900°F) under 20 MPa (3 000 psi) pressure in the presence of a cobalt-molybdenum catalyst. The fuel oil mode is targeted to produce fuel oil with less than 0.7% sulphur by weight from coal with more than 3% sulphur. The syncrude mode is designed to produce a lower-sulphur, light product. The products are primarily aromatic in nature.

An example of a pyrolysis process is the Char-Oil Energy Development (COED) process[15] in which coal is heated to successively higher temperatures in a four-stage fluidized bed system to produce oil, gas and char. The oil product is treated in a fixed-bed reactor containing a nickel-molybdenum catalyst to remove sulphur, nitrogen and oxygen. The gas is composed of hydrogen-rich compounds such as methane and ethane. The char can be used as a source of energy for power production (as seen in synthetic crude oil (syncrude)) and the tar that is formed can be hydrotreated to produce a syncrude.

The indirect liquefaction (synthesis) route has been used successfully in commercial coal liquefaction operations. Synthesis gas is produced by burning coal in the presence of steam and oxygen in a gasifier (e.g. Lurgi gasifier)[15]. After treating it in gas purification units to remove impurities such as hydrogen sulphide, tar and ammonia, the synthesis gas is converted (Figure 3) to liquid products in catalytic reactors utilizing iron and cobalt catalysts under elevated temperatures and pressures (Fischer-Tropsch Process). Mainly aliphatic (straight-chain) and olefenic (unsaturated) hydrocarbons suitable as precursors of diesel fuels and gasoline are produced (Table 1).

A variety of gasifiers, in addition to the Lurgi fixed-bed gasifier, are being investigated. These include the Koppers-Totzek entrained-bed gasifier and the Winkler fluidized-bed gasifier. The University of Minnesota-Duluth (UMD) uses the METC pressurized atmospheric stirred-bed gasifier and the Hygas process a multi-stage entrained and fluidized-bed gasifier[16]. Tar is a prominent product of the Lurgi gasification step (Table 1), constituting 15-20% of the total output and is also produced in the UMD gasifier. Much less tar, if any, is produced by the Koppers-Totzek reactor.

4. Coal Liquefaction Research and Development in Canada

Coal liquefaction activities in Canada are limited at present to small bench- or larger laboratory-scale research and development efforts. A number of process development units (PDU's) are located at governmental, industrial and university research establishments such as CANMET in Ottawa, Ontario; the Alberta Research Council, in Nisku, Alberta; the Sandwell Beak Research Group in Mississauga, Ontario; BC Research in Vancouver, British Columbia; the Nova Scotia Research Foundation Corporation in Dartmouth, Nova Scotia; and the Ontario Research Foundation, Mississauga, Ontario.

The Canada Centre for Mineral and Energy Technology (CANMET) program was initiated in 1976[13] within the Science and Technology Branch of the federal Department of Energy, Mines and Resources. It is comprised of a contract and an in-house research program. This latter program led to the construction of the first laboratory-scale, continuous flow direct hydroliquefaction unit in Canada. A second unit is now also in operation. A first priority of the research program was the coprocessing of tar sands bitumen and coal. Other priorities are related to testing the liquefaction behaviour of different Canadian coals.

The continuous hydroliquefaction units (Figure 4) operate with coal slurry feed rates of up to 1 kg/hr and have two gas feed streams to simulate synthetic gas mixtures. The maximum operating temperature is 500°C and the maximum pressure used is 34 MPa[13].

The liquid product is collected in high pressure receiver vessels located at floor level in a vented cabinet. Before release to the atmosphere, waste gases are condensed and cleaned to remove hydrogen sulphide.

Liquid products are classified as naphtha, middle distillates and residual oil. Waste gases contain C1 - C4 hydrocarbons, nitrogen oxides, ammonia and hydrogen sulphide. Samples of product and waste gases are collected at intervals in high pressure sampling containers and are transferred to laboratory sample bottles or to gas bags within a fume hood. Product samples are stored in a refrigerator.

The Alberta Research Council program in Nisku, Alberta, was initiated in 1979 and a wide range of experiments on Alberta coals is under way. Different routes are being investigated including pyrolysis, the coprocessing of coal and bitumen and a two-stage hydroliquefaction process using carbon monoxide and steam in the first and hydrogen in the second. In this process anthracene oil is used for start-up and slurried coal is fed at a rate of 2 kg/hour and reacted at 470°C and 20.7 MPa (3 000 psi). Product slurry is tapped once a day into a steel drum and transferred to a centrifuge for separation of liquid and solid products and subsequent analysis.

The two-stage process has several advantages including the potential for increased yields[17], avoidance of coking problems[18] and avoidance of the problems associated with the variability of coal quality[18]; it is also favorable for the coprocessing of coal and bitumen feedstocks[19,20] and is not adversely affected by sulphur.

The BC Research program in Vancouver, British Columbia, is based on the use of a continuous-flow unit built in 1979. It started operating in 1981 with the investigation of coal from Hat Creek, B.C., using anthracene oil and a molybdenum catalyst at 440°C and 17.2 MPa (2 500 psi). The feed rate is 1.5 L/hr. The product is approximately 60% distillate and 40% gases. Ash is low (approximately 3%).

The Sandwell Beak Research Group in Mississauga, Ontario, designed and built its facility also in 1979. A first run was completed in 1981 with the investigation of Western Lignites and low rank coals from Alberta. The starter solvent is the liquid product. Operating pressures are 20-24 MPa and the maximum operating temperature is 475°C. Either synthetic gas (syngas) or hydrogen is used as reagent gas, with recirculation of the gas after purification. The product (light, intermediate and heavy fractions) is collected at intervals of 30-45 minutes.

The Nova Scotia Research Foundation Corporation in Dartmouth, Nova Scotia, initiated process studies relating to the direct liquefaction of Nova Scotia coals in 1977 utilizing batch-type processing equipment. The original experiments related to a low-severity thermal liquefaction process, in which a low pressure hydrogenation step was followed by a delayed coking step[21]. In 1982 a continuous coal liquefaction unit began operation and they are now investigating more conventional high pressure catalytic hydrogenation processes[22,23]. The unit has been designed to operate at 28 MPa (4000 psi) and to process up to 3.0 kg of coal-oil slurry per hour. Anthracene oil is used as a starter solvent.

The Ontario Research Foundation, under contract with CANMET, has used a hydropyrolysis research unit designed to feed coal up to 1 kg/hour and hydrogen up to 5 kg/hour at temperatures up to 900°C (1652°F) and pressures up to 17.2 MPa(2500 psi)[24].

Process development units are also located at the Universities of British Columbia and Victoria in B.C. and research is being carried out also at the University of Sherbrooke, Quebec and the University of Alberta in Edmonton, Alberta. Coal liquefaction research was also previously supported in Saskatchewan by the Saskatchewan Power Corporation, the Saskatchewan Oil and Gas Corporation and CANMET. Priorities have changed, however, and no research work is in progress at the present time.

In Nova Scotia a private sector initiative is currently reviewing the research required preparatory to the possible development and construction of a hydroliquefaction process pilot plant. The construction of a pilot plant in Alberta has also been considered.

It is estimated that approximately three hundred persons have worked or are working directly or indirectly at coal liquefaction establishments in Canada. Indirect employment would include work at analytical laboratories, maintenance workers who service other projects, outside contract employees and cleaning staff.

5. Prospects for Coal Liquefaction in Canada

"While coal liquefaction cannot now be considered an immediate requirement for Canada, there are several areas in which research and development seem promising for the future. These are coprocessing with heavy oils, bitumens and residues; liquefaction on-site of large deposits of low-grade, low cost coals; and the development of new technologies that could prove economical for specific deposits such as Nova Scotia or Western coals with access to natural gas for hydroforming and appropriate high liquid yields"[25].

The process considered most likely for early commercial development is a version of the CANMET hydrocracking process[26] used for upgrading heavy oils. Trials with this process, i.e. coprocessing coal (10% or more) with heavy oils, have been carried out successfully at CANMET. Planning has also proceeded with regard to further trials at the Petro-Canada refinery at Montreal, Quebec. The proximity of coal reserves to sources of both natural gas and heavy oil and tar sands bitumen deposits in Alberta, may determine the application of coprocessing technologies in that province. For coals with a high ash and moisture content a synthesis or indirect liquefaction route may be preferred.

Various socio-economic considerations might favour the early development of a hydroliquefaction pilot plant in Nova Scotia.

II Safety and Health Concerns

1. Summary of Main Hazards

The coal liquefaction process is, for the most part, a closed system and the risk of exposure to noxious contaminants (raw materials, gaseous emissions) should, under best practicable conditions, be limited to such operations as preparation of the basic ingredients, pre-treatment, charging-up, shut-down, sampling, maintenance operations, product removal, laboratory analysis and waste treatment. However, the high temperature and pressure operating conditions under which coal is liquefied, together with the corrosive properties of the feed-stock, increase the risk of embrittlement of process equipment and the escape of gases, vapours and liquids (fugitive emissions) at valves, joints and other components. There is thus, in addition to risks of thermal burns, fires and explosions, the risk of exposure to a multiplicity of highly toxic chemical substances present in the coal liquefaction process streams. Some of the hazards present in the coal liquefaction environment, are summarized in Table 2 by process step and type of hazard.

The toxic gases most likely to be present as serious hazards are hydrogen sulphide, other organic sulphur gases such as carbon disulphide, hydrogen cyanide and carbon monoxide Ammonia and sulphur dioxide may also occur and oxygen deficient atmospheres may be encountered in confined spaces. Vapours and liquids containing phenolic and cresolic compounds are extremely irritating and may constitute as much as 30% of some streams[27]. While toxic gases and vapours are not usually present in the working environment in concentrations that exceed threshold limit values, they may constitute extremely dangerous hazards under conditions of equipment malfunction and/or accidents when their release could become potentially lethal. It should be noted, however, that threshold limit values may not be available for all the compounds potentially present in the working environment.

Coal and silica containing dusts may constitute a hazard during coal and coal-slurry preparation. Coal particles generally contain trace amounts of silica but additional "free silica" may be added in certain processes (e.g. Hygas)[28] to alter the slagging properties of coal. During maintenance operations, workers may also be exposed to catalyst dust containing nickel, cobalt and other toxic metals.

Trace elements such as As, Pb, Cd, Ni, Be, Hg, Se, are volatilized under coal liquefaction process conditions and may form a variety of organometallic compounds. Metal carbonyls including nickel carbonyl, iron pentacarbonyl and cobalt hydrocarbonyl are formed where carbon monoxide is present and may become released into the working environment by catalytic reactors during start-up and shut-down operations. Other metallic compounds, such as beryllium and arsenic may be released in fugitive or escape gases[14] or be encountered as organically bound compounds in recycle liquids and the final by-products, ash, tar and char, where the majority of the trace elements are likely to remain[28]. They are of concern because of their potentially toxic and carcinogenic properties but their concentrations in the working environment are likely to be low.

From the occupational health point of view, the most important group of substances to which workers are exposed are the aromatic hydrocarbons. Prominent among this group are the polycyclic aromatic hydrocarbons (PAH's). Many of these compounds, known to have carcinogenic properties, have been identified in the air, process stream and product samples taken at coal liquefaction operations. When released as fugitive or gaseous emissions, they may become attached to, or occur as particulates which settle out in the working environment and contaminate equipment[29].

Also found as part of the aromatic content of process streams, emissions and products are the aromatic amines (PAA's) and various heteroatom aromatics (PNA's). Certain aromatic amines are known to be carcinogenic and together with other nitrogen aromatics are becoming of increasing concern because of their mutagenic properties.

Exposure to these substances in the working environment is mainly through skin contact and inhalation. Persons considered specially at risk include those responsible for start-up charging, sampling, product removal and maintenance work. Workers contracted from outside agencies may be heavily exposed and less aware of the potential hazards.

2. Toxicity of Coal Liquefaction Products in Animal and Other Systems

The toxicity of the chemical components of coal liquefaction process streams, products and by-products have been extensively investigated in recent years, notably in the United States and many useful reports are available in the scientific literature. Only a brief general outline of the toxicity of coal liquefaction compounds is reviewed here.

The acute and chronic toxicity characteristics of some classes of coal conversion products are given in Table 3. Toxicity varies widely between classes as well as between their acute (short-term) and chronic (long-term) effects. Medium and high-boiling fractions of coal liquefaction products can elicit biochemical and hematological changes in rats[99]. A summary of selected toxicity findings by type of coal liquefaction process is given in Table 4. In general, the toxicity of indirect liquefaction products, as compared with the products from direct liquefaction, is low[16].

Varying degrees of dermatoxicity are displayed by these classes of compounds. PAHs have been reported to produce erythema of the skin and phototoxic effects[120]. Moderate eye irritation is common. The neurotoxicity of petroleum solvents, suspected on the basis of human experience, has been confirmed in animal experiments[30]. Higher boiling fractions may be embryotoxic[31,32].

Biological activity studies have indicated varying degrees of *in vitro* mutagenicity for all coal conversion products and product fractions. Alkaline (PAA and aza-arenes) and polar-substituted neutral polycyclic aromatic mutagens appear to be unique to the coal liquids and are sometimes the cause of exceptionally high mutagenic activity, with a potency that may vary between 10 and 100 times that observed for natural petroleums. In the case of natural petroleum samples, mutagenicity is due solely to the neutral constituents[33]. The results of *in vitro* bioassays suggest the following general trend for process products: H-Coal (fuel oil mode) H-Coal (Syncrude mode) SRC II COED Shale natural petroleum[33].

Both products and process streams, particularly the middle and higher boiling streams[34,35] have been shown to be carcinogenic in animals. In these cases the carcinogenic activity was generally attributed to the presence of certain PAH's known to be carcinogenic[64,121]. The carcinogenic potential of some of these compounds is reviewed in Table 5. In addition, co-carcinogenic effects may be expected as was demonstrated in the case of exposure to certain phenols[36].

Benzo(a)pyrene (BaP), the first PAH to be isolated and tested, was shown to be a potent carcinogen as well as being capable, at high dose levels of affecting reproduction in animals. Certain other PAHs produce tumours in the offspring of animals treated during pregnancy[61,62]. Some carcinogens are also teratogens[63]. In general the Fischer Tropsch products appeared less carcinogenic than the Bergius (catalytic hydrogenation) process products[15].

3. Influence of Process Conditions on the Biological Activity of Coal-Derived Liquids

The observed variability with regard to the biological activity of the different coal-derived liquids depends upon the presence of differing quantities and species of compounds and is, in turn, influenced by the rank of the parent coal used and the engineering and operating specifics such as reactor temperatures and pressures, gasifier/reactor design and the severity of hydrotreatment.

The relationship between increasing temperature and increasing quantities of polyaromatic hydrocarbon and hetero-atom aromatics, as well as the relationship between increasing boiling point of distillates and increases in mutagenicity (Ames test) and skin carcinogenicity in animals has been documented[48,65]. (A relationship between the temperature of carbonization and distillation and the incidence of lung cancer in humans has also been suggested)[66].

The design of gasifiers/reactors also has relevance. In addition to the CO/H_2 synthesis gas produced by the Lurgi (fixed-bed) gasifier, a broad range of other potentially toxic products and by-products, including tars, are produced. These tars may constitute as much as 15-20% of the total output. By comparison, no tar appears to be evolved in the process streams and product gas (Table 1) from the Koppers-Totzek (fluid-bed entrainment) gasifier[16].

Of key interest is the effect of hydrotreatment. Because of their higher aromaticity and hetero-atom content, some coal liquids require increased severities of hydrotreatment to bring their chemical and physical properties in line with natural petroleum products. Increasing the severity of hydrotreatment substantially reduces concentrations of PAHs, phenolics, nitrogen heterocyclics (aza-arenes) and PAA's. It is accompanied also by a lowering of the toxicity of the coal derived liquids. Decreases in mutagenic activity, for example[38,65,67,68] can be considerable. A 90-99% decrease has been observed at 1 000 standard cubic feet of hydrogen per barrel of feed oil (SCF/bbl) with no detectable mutagenicity beyond 2 000 SCF/bbl hydrogen consumption. Increasing hydrotreatment also results in slightly reduced acute toxicity (up to about 1 000 SCF/bbl) both for cellular and animal systems (mice). In this respect, the hydrogen content of coal derived liquids has been found to be a good indicator of acute toxicity. The skin tumour incidence is reduced at lower hydrotreating severities of about 250 SCF/bbl.

4. Coal Liquefaction Worker Health Effects

The most common of the acute medical problems encountered at coal liquefaction pilot plants in the United States have been dermatitis, eye irritation and thermal burns[6]. Gas leaks were implicated in the death of several workers in an indirect liquefaction industrial plant in South Africa[16]. Other possible acute and chronic health effects are reviewed by substance and target organs in Table 6. The acute toxicity of methanol should also be considered when the methanol route is followed in the production of gasoline.

The acute asphyxiating effect of high concentrations of carbon monoxide (CO) is well known. In cases of severe CO poisoning involving pregnant women, it is also the fetus which is placed at particular risk since reports are available to indicate that an increased number of stillbirths may occur and there is evidence of brain damage in surviving offspring[70]. The risk to fetal health may also be important at lower level chronic CO exposures and it has been suggested that exposure limits for pregnant women need to be much lower than the level proposed by the current time weighted threshold limit of 55 mg/m^3[71].

The chronic effects of solvents are receiving increasing attention. Studies in Sweden[72] and Finland[73] have confirmed the neurotoxic effects of organic solvents, including jet fuels, after long-term exposure - in some cases probably following relatively low level exposures. A recent mortality study in the United States also suggested that solvents other

than carbon disulphide may cause arteriosclerotic heart disease. Ischaemic heart disease was found to be associated with exposure to phenol[74].

No epidemiological data are available for the pre- and post-World War operations in Germany or the post-war indirect liquefaction operations in South Africa[16].

An epidemiological study, conducted in relation to workers at a direct coal liquefaction pilot plant in the United States and reported[3,35,75,76] in 1960, revealed that fifty of 359 workers suffered skin abnormalities[76]. Skin cancer was diagnosed in the case of ten of these workers, six of whom were maintenance workers. The skin cancers represented an incidence of between 16 and 37 times that reported for the general population and all occurred within ten years of commencing work in the plant. A follow-up review of the collected information confirmed the original findings as well as that no excess deaths appeared to have occurred in this group of workers from other cancers[77]. Environmental studies revealed that the pitch treatment and solids removal operations contributed significantly to air-borne contamination by 3,4-benzpyrene with a level as high as 18 mg/m^3 being recorded. Levels contrasted sharply with values quoted for community air samples of 0.0-0.1 mg/m^3[75]. Significant advances have been made in general process technology as well as in hygiene and sanitation control practices since this study was first reported[69].

At another direct coal liquefaction plant in the United States, three skin cancers were reported among 190 workers during a twelve year period of observation and plant operation[78]. Two cases occurred approximately three years after construction of the plant began, the other after approximately nine years. Details with regard to duration and type of employment as well as of skin colour, were not available.

5. Cancer Experience in Related (Fossil Fuel) Industries

A considerable body of information is available implicating coal and other fossil fuel by-products in the development of cancer among exposed workers, as shown in Table 7. Available environmental monitoring data are reviewed in Table 8. The epidemiologic evidence for the occurrence of excesses of cancer is strongest for workers exposed to the by-products of coal. Shale oil and conventional petroleum and petroleum combustion products are also implicated but apparently to a lesser degree.

Cancer of the skin of the scrotum among chimney sweeps was a prominent early finding and the occurrence of lung cancer among coke oven workers showed a consistent relationship with excessive exposure to the inhalation of coal by-products. Bladder cancer was also reported but is better known in connection with excessive exposure to substances like beta-naphthylamine in the (coal by-product) dye industry. While these substances are likely to be present in coal liquefaction streams, their concentrations are expected to be low. Cancer involving the gastro-intestinal tract, pancreas and kidney has occurred among workers in the coal industries but is now reported more frequently in relation to natural petroleum refining and there is evidence to suggest that melanoma and brain cancer may also occur[79]. These latter associations require further investigation.

It should be noted that not all studies reported positive associations between exposure to fossil fuel products/by-products and the occurrence of malignant neoplasms[80-89]. In some of these studies the quality of the information available was not adequate for epidemiological analysis.

In interpreting the available epidemiological findings, and in particular the differences observed between earlier and present day studies, a variety of factors must be taken into account. These, in addition to the different chemical configurations present in different fossil fuels, include the influence of process technology on the chemical species found in a particular working environment; the advances made in safety engineering technology on their concentrations; and the effects of improvements in hygiene and sanitation practices on the level of worker exposure.

It is probable, therefore, that levels of exposure relative to the target organs discussed in more recent reports were much lower than those for studies reported earlier. The relatively low but above ambient level concentrations of PAHs found in diesel exhaust, may explain the difficulties experienced in establishing unequivocally the relationship between exposure to diesel fumes and lung cancer[118]. In addition, it should be remembered that the baseline against which comparisons are usually made (for example, the incidence of lung cancer in a standard population), has been changing[80]. In the case of lung cancer, an increasing incidence attributed to increasing cigarette consumption, was reported, particularly for the 1940s and later decades. The effect of exposure to other sources of (urban) air pollution must also be considered since it has been suggested that PAHs such as BaP may act synergistically with sulphur dioxide and cigarette smoke[119].

Epidemiological studies pertaining to the health effects of coal conversion products on women have not been reported as yet.

III Environmental Surveillance - Industrial Hygiene and Safety

1. Industrial Hygiene Reports - From the United States

A number of reports and descriptions of Industrial Hygiene and Safety programs, notably those in the United States, have appeared and are available in the scientific literature. Among the first of these is the report on the environmental findings and surveillance procedures developed for a direct liquefaction pilot plant which operated in the United States between the years 1952 and 1959[3]. Some of the environmental findings have been summarized in Table 8. An epidemiological study, in which a high incidence of skin cancer was reported, was discussed in chapter II. Other selected reports are briefly reviewed below.

1.1 Industrial Hygiene Monitoring at H-Coal Pilot Plants[123,125,126]

A systematic approach is described in these reports for the establishment of an industrial hygiene air monitoring program in a pilot-plant-scale liquefaction facility. Elements of the program are:

- Identification of potential contaminants by plant area;
- A sampling strategy consisting of periodic area and personal sampling utilizing recognized sampling and analytical techniques;
- A computerized personnel exposure recording system; and
- Source identification with real-time air monitoring devices.

Area tests were made for coal dust, coal tar pitch volatiles, benzo(a)pyrene, aromatic amines (analine, toluidine, N,N-dimethylaniline), phenols, cresols, cyanide and hydrogen sulphide.

Personnel monitoring, in addition to the above, included benzene, toluene, xylene, hexane, carbon disulphide, nitrogen oxides, ammonia and carbon monoxide.

Results to the end of 1982, have indicated that worker exposures are typically below threshold limit values (TLV), although the average exposure to coal tar pitch volatiles was slightly above the TLV[171]. A number of contaminant sources were identified and control measures taken. Process sample technicians, pipe fitters and boiler makers consistently showed higher mean and peak values than workers in other categories.

Along with air sampling, the Ames test for mutagenicity was carried out on urine samples from PAH-exposed workers[122]. The potential value of this test procedure could not be demonstrated at the low levels of exposure found to be present in this pilot plant.

1.2 Skin Contamination Survey at the H-Coal Pilot Plant[123]

Selected workers from different job activities were monitored using a hand-held low intensity (300-800 uW/cm^2), long wave (365 nm) blacklight.

Monitoring tests were also made with a developmental quantitative instrument, called the "Spill Spotter", devised by the Oak Ridge National Laboratory (ORNL). This instrument measures the intensity of fluorescence at a distance of 10 cm from the skin. It is calibrated with a benzo(a)pyrene standard.

Blacklight monitoring of workers with marked post-shift skin contamination demonstrated that showering does remove process material from contaminated skin. Spill Spotter results were not very satisfactory because of quenching effects of materials and variable skin fluorescence. It was concluded that the extent of contaminant removal was not readily quantifiable and that additional research was needed in this area.

It was concluded that controlled use of long-wave, low-intensity blacklight in shower areas would likely benefit workers in locating and removing contamination that might otherwise be left on the skin. Brief exposure to such illumination on a daily basis was considered to constitute only a small fraction of the threshold limit value and was presumed to be of little adverse significance to health.

1.3 Industrial Hygiene Survey: Two Coal Liquefaction Pilot Plants[124]

Two facilities were examined; one a donor solvent process, the other a donor solvent/catalytic hydrogenation process. The methods used in this survey and the results are summarized in Table 9. Workers were found to be exposed to low concentrations of PNAs and aromatic amines, some of which are suspected carcinogens. Very low concentrations of benzene, toluene and xylene were also measured.

Concentrations of airborne particulates in the coal preparation area were within acceptable limits.

1.4 Industrial Hygiene and Safety at Coal Gasification Plants[8,9]

Pilot and Proto plant gasification facilities (a new full scale commercial plant has also been planned) were operated in conjunction with the local production of electricity required by a chemical processing industry. The industrial hygiene program, designed to protect the workers in these plants incorporated the following elements:

- An extensive and continuous education program comprised of comprehensive worker orientation and training (including first aid and emergencies); mandatory training sessions to familiarize workers with new equipment and procedures; regular discussions regarding hazards and results of surveys;
- Written operating procedures for all activities;
- Engineering and administrative controls to minimize or eliminate exposure to hazardous chemicals - including overlapping instrumentation systems, area monitoring instruments (fixed-place sensors and alarm systems for e.g. CO, H_2S), personnel monitoring devices (H_2S, CO, CO_2, dust); sound level meters; and oxygen/combustibles detectors (required also for vessel entry);
- Personal protective equipment, specified by task and by written procedures (hard hats, safety glasses, mouthbit respirators, hearing protection, safety shoes, fire resistant clothing, face shields, protective gloves, dust masks, etc). Safety showers and eye wash stations are strategically located. More specialized equipment include full-face supplied air respirators and a respirator-fit testing facility;
- Hygiene and sanitary facilities, (change room, showers), first aid rooms, eating areas;
- Maintenance monitoring at regular intervals to maximize equipment reliability, decontaminate equipment, etc.
- Emergency preparedness; and a
- Health team approach involving Industrial Hygiene, Medical and Safety Department personnel, together with selected project staff. Health Team responsibilities include identification and evaluation of work place hazards, through monitoring surveys.

1.5 PAH-Contaminated Materials Management[127]

A report on PAH-Contaminated Materials Management at the Oak Ridge National Laboratory[127] outlines a systematic approach to safe-guarding the health of 80-100 researchers employed in synfuels research at this laboratory. Elements of the industrial hygiene program include: area access control, engineering controls, respiratory protection, protective clothing, good housekeeping practices, monitoring of air and surface contamination, personal hygiene, educational programs and waste disposal. Personal hygiene has been found to be the most important aspect of employee protection. Barrier creams have not proven useful and may solvate material. Disposable butyl nitrile gloves are used.

2. Related Industrial Hygiene Research in the United States

A report to the United States Federal Interagency Committee on Health and Environmental Effects of Energy Technologies[128] lists research tasks in occupational safety and health aspects of synfuel production as follows:

- characterization of process streams;
- determination of fugitive leaks and emissions of concern, i.e., dermal or inhalation contact;
- determination of relative risks to workers in specific plant areas;
- evaluation of the most likely accident scenarios;
- field surveys of each synfuels process;
- development of models for the next generation of coal liquefaction plant;
- development of new and improved monitoring methods and instrumentation such as passive samplers, real-time analysers, surface and skin contamination indicators, data storage and retrieval systems;
- decontamination procedures;
- development of new or improved protective clothing and respirators, standard tests to indicate unacceptable permeation;
- development of a worker registry to permit future evaluation of exposure;
- development of improved industrial hygiene work practices and training procedures.

While the chemical composition of coal derived synfuel materials has to a large extent been characterised, not all hazards have been specifically identified and work is continuing in parallel with the development of new process technologies. Choices must, therefore, be made with regard to which chemicals to monitor from the point of view of worker exposure. A suggested listing[129] of potential monitoring requirements, based on experience in other coal industries and the results of ongoing synfuels research, is given in Table 10. Not all identified compounds can be monitored conveniently or economically, nor are all available equipment suitable for use in the working environment. Portable monitors for specific aromatic amines, for example, do not exist and recourse must, for the time being, be made to the measurement of benzene or cyclohexane solubles to indicate the potential presence or absence of related chemicals (coal tar pitch volatiles) in the workplace. The best that may be realized in practice are measurements of exposure to a few selected species and area monitoring for a variety of others[129]. Thus for exposure monitoring, coal tar pitch volatiles are generally measured along with various indicator compounds for PAHs.

The potential hazards from synergistic effects require that a variety of contaminants be measured. Carbon monoxide and hydrogen sulphide and proxy compounds, such as 2-methylnaphthalene for PNA vapours, and pyrene and BaP for the heavier PAHs, have been favoured in this regard. Carbon monoxide has, however, not been found to be a useful indicator of PAH contamination at coal liquefaction operations. BaP, because of its presence in complex mixtures of PAHs have often been used as an indicator of the carcinogenic potential of such mixtures. However, since the proportion of BaP to other potentially carcinogenic PAHs in any particular mixture may vary, determination of BaP alone cannot be relied upon to reflect the degree of risk. A number of other PAHs must, therfore, also be measured for routine monitoring purposes. The National Institute for Occupational Safety and Health in the U.S. (NIOSH) has used a profile of 29 PAHs and 7 aromatic amines[124] and the Environmental Protection Agency in the U.S. generally uses a list of 15 PAHs.

From a cost containment point of view, useful indicators may include pyrene, benzo(a)pyrene, benzo(e)pyrene, chrysene, fluoranthene, phenanthrene, anthracene and benzo(a)anthracene[130]. It is possible that refinements in analytical techniques may simplify PNA evaluation in the future[131].

Much attention is being directed to the development of improved instrumentation, particularly in connection with the measurement of exposure to PNAs. At the Oak Ridge National Laboratory (ORNL), for example, passive dosimeters are under study for PNA vapour and ultraviolet spectrometers for real-time PNA measurements in the parts-per-billion range.

While Anderson-type size-separating particulate personnel samplers were satisfactory for size characterization of coal liquefaction aerosols, cyclone-type samplers were not satisfactory[132].

Two quantitative, portable ultra-violet (UV) instruments for detection of PNA skin and surface contamination have been developed by scientists at ORNL, but are not yet in routine use in synfuels facilities. One of these instruments, the Spill Spotter[133] was referred to in section 1.2. It consists of a UV illuminator and electronic fluorescence detector. It can be used in bright sunlight at distances up to 3 metres from a surface and has also been applied to skin monitoring.

The other instrument, the Light Pipe Luminoscope[134], is designed for skin contamination only and utilizes a fibre optics light guide to conduct induced fluorescence to a photon counting detector. The sensor head, a stethoscope cap, is pressed against the skin. Fluorescence is measured on a spot 2.5 cm in diameter enabling contamination patterns on a hand, for example, to be mapped.

Because of the phototoxic and synergistic effects of UV and PAHs, there is a reluctance to use near-uv light for monitoring skin contamination and the intensity of the hand-held black light, for example, may be considered too high. In this instance the use of the Light Pipe Luminoscope with its lower intensity, may offer a useful compromise or alternative for very short exposures. It has been estimated that short, ten second exposures equate to only 1/100th of the radiant flux of sunlight.

UV examination of equipment and working areas has been found useful in demonstrating that walls and railings may become heavily coated with carcinogenic and mutagenic hydrocarbons, while not apparent to the eye.

Sampling and an analytical procedure for the evaluation of skin contamination were described[135]. In this procedure cyclohexane is sprayed onto a limited area of skin and the rinsings are evaluated by UV fluorescence. The limit of detection was 0.2 micrograms heavy distillate fuel oil. However, the cyclohexane skin washing techniques suffer the disadvantage that they may enhance PAH absorption through the skin.

New developments in real-time monitoring instruments were described recently[136]. It was noted that the detection of small leaks was important to prevent the potential for exposure, particularly excessive exposure to acutely toxic compounds and to carcinogens. A number of instruments under trial and development at ORNL were described. These included portable gas chromatographs and infra-red spectrometers. Of particular interest are a real-time paper-tape PNA instrument based on phosphorescence and various skin and surface UV instruments[137].

A high volume sampler consisting of a teflon filter and resin-absorbent bed, which combined with a gas chromatograph/mass spectrometer/data system[138], enabled the identification of numerous organic compounds in the vicinity of a coal liquefaction plant. The sampler operates at 35 litres per minute.

A review of worker protection practices[130] at five U.S. coal liquefaction pilot plants emphasized protective clothing, personal hygiene and a need for worker education.

Protective clothing is continually under study in these pilot plants. Cotton has generally been found to be more satisfactory than synthetics, although a new polyester-cotton fabric incorporating a stainless steel mesh is being tested in an effort to improve durability. Disposable vinyl rainsuits for hydroblasting and heat protective clothing for sampling are used at some plants. Procedures for dry cleaning and laundering of clothing are carefully controlled[130].

A variety of gloves has been used, including those made from vinyl and neoprene. However, a recent study of the permeation of gloves used in coal liquefaction pilot plants concluded that milled nitrile laboratory gloves provided the best protection[139]. Safety shoes are generally provided along with disposable vinyl overshoes or steel-toed rubber boots.

While airline and self-contained breathing units are used for respiratory protection, it has been found that for low level exposures, disposable-type organic vapour and dust respirators are prefered to establishing cleaning and sanitizing facilities for cartridge-type negative pressure respirators.

In comparing industrial hygiene programs for coal gasification, coal liquefaction, oil shale and tar sands processing, it was considered that a single program, comparable to that used at the Solvent Refined Coal pilot plant at Fort Lewis, Washington, could be made applicable to all[140]. The review warned against too much reliance on barrier creams and called attention to the need for a procedure to evalutate skin contamination, more detailed air monitoring, for example for aromatic amines and detailed process profiles.

3. Safety Practices at Canadian Research Facilities

The continuous flow process units currently in use by Canadian researchers are small with through-put capacities of 0.5 kg/hr to 10 kg/hr. The operating temperatures vary from 400°C to 500°C, and pressures up to a maximum of 34 MPa (5000 psi). (Pyrolysis experiments are carried out at temperatures of 800 to 1000°C and pressures up to 17 MPa (2 5000 psi)). In most cases the starter solvent is anthracene oil. Either synthetic gas or hydrogen is used as reagent gas. Operating times vary from 10 to 120 hours. Liquid products are

generally collected in high pressure receiver vessels and waste gases are cleaned to remove hydrogen sulphide before release to the atmosphere.

All process development units are housed in large workroom or laboratory-type facilities which are shared with other research programs. Extensive use is made of local exhaust ventilation systems for venting operations such as coal grinding, slurry feed, product removal, sampling and equipment maintenance. Make-up air generally enters the work areas through supply units located at ceiling level.

All units are also shielded by barriers such as Lexan or steel-reinforced concrete (the units in one facilitiy were previously housed in bell-shaped, steel-walled containment cells). Alarms are provided and maintained for toxic gases including hydrogen (H_2), hydrogen sulphide (H_2S) and carbon monoxide (CO).

Personal protective equipment provided includes face shields, hard hats, protective clothing, gloves, respirators and safety shoes. Protective clothing consists of coveralls and laboratory coats which are dry-cleaned periodically by a commercial dry cleaner. There is no regular schedule for changing clothing. Safety shoes are left at work. Leather, neoprene and disposable vinyl gloves are worn as required. Filter-type respirators are worn by operators at some operations such as coal preparation.

Safety showers, fire blankets, eye-wash stations and First Aid Kits are generally available. Showers are also available and are recommended for after-work use. No special arrangements are made with regard to lunch room facilities at present. Separate lockers for clean and work clothing are not available. Workers are instructed in the use of emergency procedures and equipment and safety officers are designated. Safety Committees have been appointed but are generally responsible for health and safety issues relating to all research being carried out on the premises.

Despite the general level of awareness about the nature of the hazards associated with coal liquefaction, there is still inconsistency in the application of the necessary safety procedures in Canadian establishments. There is also not as yet any requirement for the regular monitoring of hazardous substances in the various coal liquefaction working environments.

4. Environmental Monitoring Reports: Canadian Operations

4.1 Identification of Airborne Organics at the Sandwell Beak Research Group Test Facility[141]

Airborne organic substances were studied at the Sandwell Beak Research Group test facility, Mississauga, Ontario during the processing of a sample of Estevan Lignite. The operating conditions were described as follows:

Coal Type:	Estevan Lignite 2% moisture, 16.7% ash
Reactor Temperature:	440°C
Reactor Pressure:	2.41 MPa
Reactor Gas Composition:	Run 513 - 60% H_2, 40% CO Run 514 - pure H_2, no recycle
Gas Feed Rate:	1.2 m^3/hour
Slurry Feed Rate:	6.0 kg/hour
Sampling Period:	6 - 12 April 1983.

Nine low volume air samples were collected at breathing level in coal slurry preparation, charging, product collection and solid separation areas for 10-30 minute periods at 0.1 L/minute. Two high volume air samples were collected at charging and product removal areas for periods of 5.25 hours at a sampling rate of 10 L/minute. Analyses were made by gas chromatography/mass spectrometry.

The low volume sampling train consisted of glass wool, glass beads, Tenax - GC, Ambersorb XE-340 and charcoal. The high volume train consisted of a glass fibre filter - approx. 0.5 mm, XAD-2, Ambersorb XE-340 and charcoal.

Qualitative test results by compound class, are summarized in Table 11 in relation to sampling area. Polynuclear aromatic hydrocarbons predominated in the slurry and product sampling areas. Substituted benzene compounds predominated in the product separation area.

4.2 Determination of the Exposure of Workers to Organic Contaminants in the BC Research and CANMET Coal Liquefaction Plants[142]

Area and personal air samples were collected at coal liquefaction experimental operations at BC Research in Vancouver and at CANMET in Ottawa. Seventy samples were collected at BC Research, fifteen at CANMET. Samples were analysed for total and individual polynuclear hydrocarbons (PNAs), simple aromatics, nitrogen-containing aromatics (N-PAHs), polynuclear aromatic amines (PAAs) and phenolics. At BC Research, measurements were also made of the contamination of gloves worn by technicians. Air sampling and analytical procedures were as specified by NIOSH or the B.C. Workers' Compensation Board. Test results are summarized in Tables 12 and 13.

Concentrations of all air contaminants measured, for which there are threshold limit values (TLVs), were within the suggested limits with the exception of Total PNAs (Polynuclear aromatics-coal tar pitch volatiles) which were excessive during slurry preparation and maintenance operations. Most of the constituents listed were not detectable by the methods used in the survey.

Individual PNAs ranged up to 9 $\mu g/m^3$. No TLVs exist for these compounds, although a limit of 0.2 mg/m^3 has been proposed for benzo(a)pyrene. The sampling system for PNAs was found to be unsatisfactory for vapour-phase components.

Work gloves were found to be contaminated with benzene-extractable material.

It was suggested that process variables such as coal type, solvent, pressure, temperature and retention time had no detectable effects on the composition or concentration of

airborne contaminants and that the extent of equipment maintenance was the most important factor in controlling emissions.

4.3 Studies at the Alberta Research Council's (Nisku) Facility

A limited study, to examine the nature of the polycyclic aromatic hydrocarbons (PAHs) present in the working environment, was carried out at the Nisku facility of the Alberta Research Council[143].

Particulate matter was collected near the slurry tank on filters at a rate of 2 L/min for seven hours and extracted by capillary column gas liquid chromatography. Up to 14 major compounds were detected in the air samples. A personal sampler revealed up to 40 major compounds in the 2 to 5 ring structure range. The measured concentration for pyrene was 4.2 mg/m^3.

Low molecular weight samples were collected by the charcoal tube method and analysed. The only low molecular weight compounds retained by the charcoal were benzene and toluene which were present in concentrations of 0.07 and 0.1 ppm respectively in the slurry tank area.

Bulk samples of starting and finishing products were also collected. These consisted of feed slurry material, naphtha and water, product light oil and hot centrifuge product. Seventeen PAHs were identified of which several are known to have carcinogenic properties. Most (% by weight) were found in the feed slurry material and the hot centrifuge product, with a lesser amount in the product light oil[143] as shown in Table 14.

A noise survey, undertaken as a separate study, indicated that noise levels in the work areas did not exceed the Occupational Exposure Limit for Alberta. The highest level measured was 78 dB[144].

5. Research Directions in Canada

Canadian biological research, supported by federal, provincial governments and private organizations, has been directed towards:

- characterization of process streams, emissions, products and by-products;
- identification of a wide range of chemical compounds;
- animal toxicity and biological activity (mutagenic effects) studies on light, intermediate and heavy distillates; and the
- development and/or refinement of area and personal monitoring techniques and analytical methodologies.

The research on monitoring methodologies was developed in close collaboration with the health surveillance initiative of the Department of National Health and Welfare and ongoing toxicological investigations of selected coal liquefaction products and by-products. It involved extensive monitoring of air quality and personal exposures at a direct coal liquefaction facility (CANMET); the search for improved chemical analytical methods; and the development, evaluation and validation of a passive sampling method for selected organic compounds such as benz(a)anthracene and amino-biphenyl. Much of this work is still in progress but some preliminary results have been published[99]. The composition of a medium-boiling (154-378°C) liquefaction product is given in Table 15. Brief summaries of available information about other studies were given in sections 4.1, 4.2 and 4.3 above.

6. Guidelines for Industrial Hygiene Control Measures

6.1 General Guidelines for Canadian Facilities

General guidelines for industrial hygiene control measures and exposure monitoring at experimental coal liquefaction operations, such as those existing in Canada at the present time, are given in Appendix A.

The guidelines have as their objective the development of an industrial hygiene program designed to minimize exposure to physical and chemical hazards in the working environment by engineering and administrative control measures, the proper orientation of workers - including contract workers - to potential hazards, written procedures for job activities, use of safety equipment and emergencies, use of appropriate personal protective equipment, area and personnel monitoring, good housekeeping and hygiene practices, continuous worker education, and an equipment maintenance program. All guidelines should be reviewed with the respective government authorities before implementation of programs to ensure compliance with locally prescribed standards and regulations.

In the interest of worker health and safety in the future, it would be important for industrial hygiene and safety personnel to be involved in the planning phase of Pilot and Commercial scale operations, that is, before construction begins. They should review all process description documents and diagrams to identify potential health and safety hazards and make recommendations for their control. Such a review should be considered the beginning of an ongoing industrial hygiene and safety review process which will continue through start-up of the plant and remain active for the duration of its operation.

6.2 Useful References Relating to Synfuels

The National Institute of Occupational Safety and Health (NIOSH) and the Oak Ridge National Laboratory (ORNL) in the United States have published extensive reviews of the industrial hygiene and safety related to coal liquefaction operations[6,16,55,124].

Other published guidelines might be helpful in specific situations. For example, a recommended standard for coal gasification[145] is applicable to indirect liquefaction operations. A document on PAH exposure in oil refineries[146] should be studied in relation to the coprocessing of coal and heavy oils. Published guidelines for electric utility use of coal-derived fuels[147] may be of interest to operations where coal liquids are transported or processed.

A series of Pollution Control Technical Manuals (PCTMs) has been issued by the United States Environmental Protection Agency, in which available data on synfuel waste stream

characteristics and pollution control technology are summarized. Directly concerned with coal liquefaction are manuals on Lurgi-based indirect coal liquefaction[148] Koppers-Totzek based indirect coal liquefaction[149] and Exxon Donor Solvent direct coal liquefaction[169]. Three other manuals deal with oil shale processes. There is also a manual of control technology appendices applicable to all PCTMs[150].

The manuals contain extensive discussions on how emissions can be controlled and would be a valuable source of information for industrial hygienists concerned with new plant developments.

Of particular interest for the protection of coal liquefaction workers are discussions in each manual on the control of fugitive organic emissions. Such emissions from pumps, valves, drains, etc., would likely be the primary source of exposure to polycyclic aromatic hydrocarbons. Control methods described include leak detection techniques, monitoring plans, preventive maintenance and equipment specification.

The Australian Committee for Occupational Health and Safety in Coal Conversion has also published a review of the subject[151] and developed guidelines for occupational health and safety similar to those discussed above. European programs have a similar content. However, additional emphasis is placed on the epidemiology of occupational disease in the general context of the natural and synthetic fuels industry.

IV Health Surveillance - Medical Aspects

1. General Considerations

The overall aim of medical surveillance or monitoring is the prevention of occupational disease. A major emphasis in the case of coal liquefaction workers is the prevention of occupational cancer, particularly skin cancer. Many other physical and chemical hazards are present in the working environment, and because of the particular nature of the coal liquefaction process, there is always the possibility of an emergency situation developing. Secondary objectives of a health surveillance program are to determine the fitness of workers for tasks to be assigned, to follow changes in the health status of employees over time and to assess whether any correlations can be established between those changes and the working environment, and to fulfill regulatory requirements.

The implementation of medical surveillance requires:

- a well-defined policy with regard to the provision of occupational health services;
- suitably trained health (and first-aid) personnel, with an aptitude for and interest in worker health;
- adequate health facilities, suitably equiped (to treat acute injuries and assist in complete and early rehabilitation of the employee into the work force);
- a medical monitoring program adapted to the specific health needs of the coal liquefaction worker;
- a record-keeping system that will allow correlation of health information with personal work history and environmental exposure data.

Only the medical program will be discussed here. A record-keeping system with emphasis on the operation of a central Worker Registry will be discussed in Chapter V.

2. Medical Surveillance Practices in the United States and Elsewhere

Pre-employment and annual periodic medical examinations, supplemented by a range of laboratory and other special investigations generally form the basis of all medical surveillance programs in the U.S. Medical examinations upon retirement of workers have also been recommended[6]. Programs differ, however, with regard to the scope of special investigations[130]. Examination of the skin and investigations relating to the respiratory system, liver and kidneys figure prominently. In some instances skin examinations are supported by the maintenance of a photographic record and in one reported instance, early surgical treatment of suspected lesions became a special feature of the program[152]. A general review of selected U.S. medical programs is summarized in Table 13[130]. Two special issues dealt with in the design of these programs are the health protection needs of maintenance workers and the assignment of women to the coal liquefaction workplace.

The special nature of the risk, due to the potentially heavy exposure to which maintenance workers and outside contract workers may be exposed has been referred to frequently in published reports. Providing suitable health protection to these workers presents difficulties, not only because different employers are often involved but because of the irregular and infrequent periods of work and the varying durations of exposure. It is of interest to note, therefore, that one of the five medical surveillance[52] programs reviewed in Table 16 made provision for contract workers to undergo medical examinations when these workers worked in regulated areas for more than 30 days per year. In two other cases, medical examinations were required after 90 days work per year.

With regard to the work assignment of women, two of the five plants preferred to place a restriction on the hiring of women as coal liquefaction workers, presumably on the basis of potential fetal toxicity effects.

3. Current Medical Surveillance Practices in Canadian Facilities

Formal occupational health programs are in place in two Canadian facilities. The Alberta Research Council has a well-developed occupational health policy, employs a full-time occupational health nurse and makes occupational physician services available. Medical examinations of all personnel are scheduled annually and special skin screening examinations are carried out every six months. The employees of the CANMET program are covered by the occupational health policies and services of the federal public service. Medical examinations are carried out every two years. An occupational health nurse visits the facility and counsels employees on an annual basis.

General arrangements for emergency care are in place for all facilities.

There are no restrictions with regard to the employment of women.

4. Elements of a Medical Surveillance Program for Canadian Workers

Medical surveillance depends upon the regular monitoring and evaluation of the health status of workers. The elements that are required to maintain health surveillance activities

include: a review and up-dating of personal health and work related histories, pre-employment (base-line) and periodic (follow-up) medical examinations, laboratory investigations and the promotion of health and safety.

4.1 Occupational, Personal and Family Health Histories

Occupational, personal and family health histories are important in the baseline and follow-up medical assessments of an individual's health status. Certain aspects of the information to be collected requires special emphasis.

All previous job activities and exposures to physical and chemical agents in the work place, particularly those with a potential to cause cancer and/or injury to such organ systems as the skin, liver and kidneys need to be reviewed carefully. That personal lifestyles or self-imposed risks such as smoking and hobbies involving chemical substances may have a very deleterious effect on health status is well accepted. A particularly difficult question, from the epidemiological point of view, relates to the information about the extent of off-work or previous work exposures to, for example, the PAH compounds. For the benefit of future epidemiological studies it may be prudent to begin to accumulate and record available exposure information.

Although normally reviewed as part of a full medical appraisal, detailed family histories are not always collected in a systematic manner. That this should be done is suggested by the accrueing experimental evidence that some of the substances to which coal liquefaction workers may be exposed have effects that may become directly transferred to their offspring[153].

4.2 Routine Medical Examinations

A complete physical examination of all organ systems, supported by selected special investigations and laboratory procedures are the essential elements of base-line medical examinations. All observations are recorded and provide a useful baseline against which future comparisons of the individual's health status can be made. Pre-employment examinations also provide an opportunity to assess an individual's physical capacity to perform the work assigned, as well as the ability to wear protective equipment such as respirators.

In periodic follow-up medical examinations, emphasis is placed on the early detection of deviations from the previous examination, the assessment of their occurrence in relation to possible occupational factors and the institution of remedial measures at the earliest opportunity.

The type and severity of exposure and the individual worker's previous health status and age usually determines the frequency with which periodic medical examinations are made. An interval of two years between full medical examinations may be reasonable in the case of usually healthy workers.

Baseline and follow-up medical examinations should be made available to all coal liquefaction workers and laboratory personnel and should be extended to maintenance/contract workers who spend more than a specified period of time (e.g. 30 days or more) in the coal liquefaction workplace.

4.3 Interim Health Assessments

Because of the nature of the coal liquefaction working environment, it may be desirable to arrange for more frequent employee health consultations. These could be carried out at regular intervals towards the middle of the period between scheduled periodic medical examinations, thus providing for an evaluation of health at least on an annual basis in the event full medical examinations are scheduled on a two yearly basis.

Interim Health Assessments could be comprised of a general review of the health of the worker (the use of questionnaires could standardize this part of the assessment), examination of the skin, recording of certain physical parameters such as blood pressure, a selected core-group of laboratory tests and an evaluation of the use of protective clothing and equipment. The assessment could be performed by an occupational health nurse and workers could be referred to a physician for a more detailed examination if required by the health status of the individual at the time, or the nature of the exposure experienced in the workplace.

4.4 Special Investigations: Criteria for their Use and Periodicity

The special investigations or laboratory tests that should be considered when designing a medical program for coal liquefaction workers are:

- a chest X-ray;
- an electrocardiogram;
- pulmonary function tests;
- an audiogram;
- a complete blood count;
- selected clinical laboratory tests including those for liver function;
- urinalysis; and
- other special investigations that may be indicated including tests used in biological monitoring, urine and sputum cytology and tests to investigate exposure to mutagenic substances.

A postero-anterio chest X-ray (36cm x 43cm), and various pulmonary function tests (e.g. FVC and FEV 0.1 sec), should be considered as part of the complete pre-employment physical examination. The frequency with which these investigations are to be carried out thereafter depends upon the type and severity of exposure and other health related factors. In the case of healthy workers in Canadian coal liquefaction establishments, it is possible that they need not be prescribed more often than at intervals of three to four years. Electrocardiographic examination, while an essential part of the pre-employment medical examination, may not be indicated for the healthy individual more frequently than

recommended by the Canadian Task Force on Periodic Examination[154], namely every ten years up to the age of 59 and then at five yearly intervals thereafter. Where a significant noise hazard exists, audiographic examinations should be carried out as determined by the respective federal or provincial authorities.

A special-care group of supporting laboratory investigations normally forms part of a complete medical examination. (Selected tests can also be done at the time of the interim health assessment). These tests may include a full blood investigation (determination of haemoglobin concentration, haematocrit, red blood cell count, reticulocyte count, white blood cell count and white blood cell differential count), certain tests for liver function (which may include serum bilirubin, serum glutamic oxalacetic transaminase (SGOT), serum glutamic pyruvic transaminase (SGPT), gamma glutamyl transaminase (GGTP) and isocitric dehydrogenase, and analysis of the urine, including microscopic examination. If kidney dysfunction is suspected, more specific renal function tests should be done.

Selected biological monitoring tests are reviewed briefly in Table 17. Biological monitoring has value in determining exposure to certain toxins in the working environment but should not be relied upon at the expense of a rigorously implemented environmental control program.

Exposure to lung and bladder carcinogens focused attention on the possible value of urine and sputum cytology, particularly because of the promise offered by early diagnosis for effective remedial intervention. They have, however, not enjoyed unqualified success nor have they found general acceptance. In the case of sputum cytology, for example, there are difficulties in obtaining samples of consistent quality and in interpreting early cell abnormalities. While certain investigators hold these tests in high regard, the merit ascribed to them would seem to depend heavily upon accumulated long-term experience in their interpretation. Urine cytology as a special investigation may find greater acceptability but the general application of this investigation may be questioned on the basis that the observed levels of the naphthylamines, the best known of the bladder carcinogens, have thus far reported to be extremely low in coal liquefaction operations.

To investigate the effects of exposure to mutagenic materials biological tests such as chromosomal analysis of circulating lymphocytes and analysis of the mutagenic activity of the urine of exposed workers have also been recommended[155]. However, factors which may mitigate against the general introduction of these tests include: the generally low concentrations reported thus far for agents or substances known to give positive results; the presence of confounding exposures (for example to the PAHs in the general environment and in cigarette smoke[122,156], and the inability as yet to interpret results in terms of whether an excessive exposure has occurred. Proper validation and standardisation of these tests still need to be done[170]. Their general applicability to health surveillance of coal liquefaction workers is, as a consequence, still limited. When used they should preferably form part of a well-defined research program.

Whatever the nature of the test or special investigation, it is clear that the occupational health physician should have a thorough understanding of the nature of the coal conversion process and its products as well as the levels at which they occur or are likely to be present in the working environment. Under these circumstances the physician should retain a considerable degree of discretion with regard to the selection and periodicity with which special procedures are carried out. A frequency for some of the elements of a medical surveillance program is suggested in Table 18.

5. Emergency Preparedness

Emergency preparedness is part of good occupational health and safety practice. To know what to do, to have the right emergency equipment at hand and arrangements in place for emergency medical evacuation and treatment at the closest health facility should it become necessary, are essential to emergency preparedness and the required pre-requisites for the saving of lives and the prevention of disability.

Emergency health procedures should be elaborated in procedure manuals and all employees should become competent in their execution. Personnel fully trained in the principles of first aid and the use of emergency equipment should be on duty at all times and supervisors on each shift should have the clear authority for the co-ordination of all emergency operations.

6. Worker Education and Participation in Health Maintenance

Worker education is a continuous process. In addition to training sessions aimed at familiarizing personnel with all procedures, regular sessions should be held to practice emergency procedures, review the operation of new equipment, review the control of workplace hazards and discuss the results of industrial hygiene surveys.

Increasing emphasis is being placed on the promotion of worker participation in personal health maintenance[74] in the belief that the motivated worker is also a more responsible worker, not only in terms of a safer working environment, but also in pursuit of improved personal health goals. With proper encouragement, these goals may become a lifetime pursuit[157,158] in which the worker's personal physician may begin to play an increasingly important part, should the worker change employment or as the worker gets older and approaches the age of retirement.

Worker participation should also ensure access to the worker's personal health information and with permission, the sharing of relevant information, on a strictly confidential basis, between the occupational health physician and the worker's personal physician.

7. Research in Support of Medical Surveillance

The quality of medical surveillance depends upon the application of the best available scientific knowledge. To this end some medical programs in industry are also involved in various aspects of toxicological or clinical research. A number of priority research areas of importance to medical surveillance of coal liquefaction workers suggest themselves and include:

- toxicity and biological activity testing of all process liquids and products relevant to coal liquefaction processes to be developed in Canada (development of toxicity and biological activity profiles);
- development of "real-time" personal exposure equipment;
- developing simplified PAH skin exposure dosimeters;
- development of more effective skin decontamination procedures;
- validation and standardization of biological monitoring procedures;
- examining the usefulness of certain enzyme systems as indicators of exposure (e.g. aryl hydrocarbon hydroxylases).

V Development of a Health Surveillance Record System

1. Introduction

The purpose of a record system or database would be to gather, sort, transmit, store, retrieve, analyze and utilize information relative to the health of workers and to the potentially harmful factors present in their working environment. In the shorter-term the objective would be to assist in monitoring, maintaining and promoting employee health, and to monitor workplace conditions and control environmental factors and agents. In the longer-term, medical follow-up and epidemiological research (studying trends in symptoms, illnesses, diseases and measuring, for example, the risk of developing cancer) would be facilitated and the effectiveness of health and environmental surveillance procedures could be evaluated.

Because of the difficulties inherent in the study of working populations over time, the information to be gathered must be accurate, properly validated, specific and sufficient for the kind of analysis and outputs envisaged. This means that choices, based on the best available scientific judgement, must be made at the outset about what should be included. The system must also be simple to operate, economic, and must remain flexible or open ended to allow for expansion of the database, if and when required. The information to be collected must be standardized, particularly when obtained from a variety of sources, and must allow for the unambiguous identification of individuals for purposes of epidemiological research, including the cross-matching of stored information with other sources of morbidity and mortality as well as other occupational health data banks. It must also ensure confidentiality.

The cost involved in establishing a computer-based record system is an important factor in deciding whether to purchase one of the commercially available systems or to develop a system more in tune with the requirements of the particular situation. Cost containment strategies may also require consideration of a phased-in approach over time and or limiting the amount of information to be collected and stored to a reasonable minimum. However, in deciding upon a strategy, cognizance must be taken of the limitations that may be placed on the ultimate usefulness of the system for epidemiological research.

In the general review that follows, attention was focused on a reasonable minimum of information related to the health surveillance and long-term follow-up of Canadian coal liquefaction workers. The review also takes into consideration the possible development of a central Worker Registry for coal liquefaction workers. This has been prompted by the fact that coal liquefaction workers in different parts of Canada are at present employed in small organizations or research establishments that may lack adequate record keeping systems. Additionally, there is a need to develop procedures for the medical follow-up of coal liquefaction workers as they leave one type of employment for another.

Providers of information, that is, the respective health surveillance programs that participate in a Worker Registry, may also become the principal users of centrally stored information. Since the collective experience of a much larger population of workers would become available to them than that which would fall within their immediate purview, health program managers may be better equipped in providing health protection for their own employees. Furthermore, a central Worker Registry would ensure the degree of uniformity and comparability of information essential for epidemiological research purposes.

Periodic audits of all sub-registries (programs covered by the system) would be required to evaluate the utilization of the system and the quality of the data inputs. In addition, protocols or Quality Assurance Manuals should be prepared in connection with all elements of the system.

2. Types of Information to be Collected

A general "listing" of health and exposure information elements, based on an estimate of some of the final outputs of a health surveillance system, is given in Appendix B. The listing is not an exhaustive compilation. Five modules or sections of information, have been envisaged. They are compatible with the phasing-in of a computerized database and contain information relating to: Employee Identity, Lifetime Occupational History, Health Status Profile, Personal Exposure Profile and Supporting Data.

2.1 Employee Identity

Personal identifying information, together with information about previous work experience as well as duration of work and work absences is normally collected first by the personnel department. From the medical surveillance and particularly the longer-term epidemiological follow-up points of view, however, the information retained by the personnel department is often incomplete. It may become necessary, therefore, to ensure that enough information is available to ensure the unambiguous identification of all individuals[129]. This will allow the cross-matching of the collected occupational health information with other sources of morbidity and mortality data, when required for statistical

studies. The information elements listed in Section A of Appendix B is a suggested minimum listing of items compatible with longer-term follow-up activities.

Much of the information that would be required is already available in personnel departments because of the need to retain information about employee identity and the starting and end points of any worker's employment. In addition to an employee's name, for example, it is a statutory requirement in Canada to record also the Social Insurance Number.

The extent to which the information currently available in Canadian coal liquefaction establishments agrees with the minimum listing outlined in Appendix B, is reviewed in Table 19. Also included for comparison are the information elements used by other data banks such as the National Radiation Dose Registry, the National Cancer Institute Reporting System, the Mortality Data Bank of Statistics Canada and the information normally available from death certificates.

Where Social Insurance Numbers have been available they have proved to be reliable in approximately 99% of attempted crossmatchings. They are, not however, absolute or unique lifetime identifiers. They do not appear on death certificates, and cannot be obtained for the purposes of a registry without the consent of the individual.

The allocation of a specific project or Worker Registry number for each employee, would in any case be indicated and may well serve as the specific or "unique" identifier for record system or Registry purposes.

2.2 Lifetime Occupational History

Apart from a limited amount of information, primarily pertaining to experience and qualifications for a particular work assignment, information concerning previous occupations is generally not collected on a systematic basis. As a consequence, the health implications of previous occupations are not assessed except where these may be reviewed by health personnel during health evaluations carried out as part of a medical surveillance program, but even then the occupational history may not be recorded in a sufficiently standardized manner to meet the requirements of a centralized data collection system.

The Lifetime Occupational History module (Section B, Appendix B) has been designed, therefore, to contain elements relating to the entire working life history of the individual. It encompasses information elements relating to current employment, all previous employment (including a review of special risks), changes in work assignment within the coal liquefaction industry or employment elsewhere. It should deal also with absences from work, changes in duration and/or type of work assignments and retirement.

The Occupational History form shown as an example in Figure 5, provides for the collection of potentially useful information about past exposures to harmful substances or agents. Provision has also been made for individuals to include a personal assessment of the severity of such exposures. Although these estimates will reflect personal experience and/or biases, they are expected to be useful as indications of the extent to which previous exposures may have occurred or affected health status. The estimates of previous exposure would be particularly useful when they are tempered by knowledge and/or informed judgement about the type of industry involved. Analysis of the estimates would also address the need of the employee with regard to personal concerns about the type of exposure experienced.

It is to be noted that only information about the "Type of Industry" is asked with respect to past employment. This has been done to avoid creating gaps of information with regard to the nature of the industry and hence the general nature of the hazards that may be present. Simple company names such as E.J. Smith Ltd., may not provide enough information even though a description of activities is given and the hazards encountered have been identified.

2.3 Personal Health Status

The Personal Health Status is intended to cover all information elements relating to or with a potential to affect the employee's personal health.

Much of the information required is obtained at the time of the individual's pre-employment medical examination and is updated regularly with information obtained subsequently at periodic medical examination, interim health assessments and visits to the occupational health unit. It is comprised of a personal as well as a family health history, information about self imposed risks such as smoking, medical examination and interim health assessment findings, the results of special investigations, and a history of other health related events, including health consultations and absences from work. The collected information is expected to assist in the early detection of adverse health effects, as well as contribute more to medical follow-up (longer-term morbidity and mortality studies).

The recording of a detailed family history is becoming increasingly important and is an area receiving increasing attention by epidemiologists[159] because of the potential of certain polycyclic aromatic hydrocarbons, some of which are also expected to be present in the coal liquefaction environment, to adversely affect foetal health. The types of information that might be helpful is shown in Figure 6.

In this example, applicable to both male and female workers, the questions have been formulated in order to elicit information about the health status of the family members of coal liquefaction workers and includes information about possible genetic effects among workers' offspring (Question 3). The purpose of question 2 is to elucidate the contribution that the spouse may make to fetal effects through work or recreational activities. The birth order and birthdates of the children should discriminate between periods of work before and after entering, for example, into a coal liquefaction work assignment. Question 4 specifically excludes all mention of abortion. Its objective is further clarification of abnormal birth or fetal effects.

The questionnaire, as shown, does not constitute a detailed investigation of reproductive history. Its main contribution is expected to be that of a prompter, that is, to allow the examining physician or nurse the opportunity to delve more thoroughly into the possible causes for any of the abnormalities reported.

It will, also, not provide information about infertility. It is to be noted in this connection that an instrument (questionnaire), based on a probability function, has been developed[160,161], and that it had been used successfully in an industrial setting where exposure to chemicals known to induce infertility occurred. Its reported sensitivity was sufficient to identify infertility effects at an early stage. Separate questionnaires for males and females were designed and consideration could be given to using these procedures in addition to a form similar to the one described above.

Recording information about self-imposed risks, such as smoking, is of particular importance to the eventual conduct of epidemiological studies and needs to be recorded as accurately as possible. Information about potentially harmful exposures to noxious substances during the pursuit of hobbies also needs to be recorded. This type of information is not available in sufficient detail at present.

In view of the special needs in this area, consideration could be given to the introduction of a special questionnaire for use at the time of the pre-employment examination. An example is shown in Figure 7.

Various medical examination forms currently in use have proved their usefulness for medical examination purposes. However, the special requirements of a coal liquefaction Worker Registry and the need to provide for standardized approaches when information is to be collected from a variety of different data sources may require the development of a new form.

The reporting of absences is normally a personnel department function. It is important that all information concerning absences be shared with the occupational health personnel involved in the health surveillance of coal liquefaction workers.

First Aid Treatment and Accident Record Books used in industry as a requirement of Worker's Compensation Acts (in the case of the federal public service, procedures are outlined in TB PROC 4-1), provide potentially useful information about occupational injuries and illnesses. Their use for health surveillance purposes should be explored.

2.4 Personal Exposure Profile

The Personal Exposure Profile attempts to provide information relative to the extent, duration and frequency of potential exposures to carcinogenic chemicals or other hazards in a given work area. It is concerned with the duration spent by individuals in such work areas. It will also require measurement information (levels of exposure) and will largely be concerned with elements of industrial hygiene surveillance including the results of personal monitoring, real time area monitoring and periodic area sampling. Duration of exposure data should be obtainable from personnel departments where records of the time worked are maintained for salary/pay purposes. From the point of view of a Registry, a more appropriate system of recording duration of exposure by specified work place or area may have to be developed (worker tracking) depending on the degree of sensitivity required for exposure/duration monitoring purposes.

2.5 Supporting Information

The module dealing with Supporting Information is intended to provide for the recording and storage of information about the technologies used as well as a record of process changes made and other operating data that may affect exposures: inventories of materials and all chemicals found, used and stored in the workplace; descriptions of the sampling and analytical methods used, by whom and when (dates of surveys); health and accident data codes; industry and work classification codes; vocabularies; general environmental (ambient) and process stream monitoring data; as well as all other information useful to support the functioning of the health surveillance system.

3. The Transmission of Data to a Worker Registry

Economy in terms of resource requirements and health data that are recorded accurately and transmitted while maintaining the desired degree of confidentiality are factors important to the successful operation of a Registry system.

There are a number of options for the routine transmission of confidential health information. A copy of the original record, such as the medical examination form could be forwarded. This will, however, require modification of the forms currently in use to eliminate positive identification of the persons involved. Alternatively the information could be forwarded on a form suitable for translation to magnetic tape. The design of the form could at the same time be adapted to serve the occupational health unit as a summary of the health information generated monthly, quarterly or even on an annual basis.

The information that would be required by a Registry for health surveillance purposes is summarized in the outline shown in Figure 8. It contains a minimum amount of identifying information necessary to access the Registry. For each of the employees, the type of health surveillance event that may apply i.e., Pre-placement medical examination (PPME), Periodic Medical Examination (PME), Interim Health Assessments (IHA) made periodically instead of a full medical examination and Consultations (CON) referring to all other contacts with the occupational health staff is indicated. In the latter case consideration could as well be given to assessing the value of the First Aid or Injury and Illness reporting forms as prescribed by Worker's Compensation Acts or other Regulations, particularly in circumstances where health personnel are not always available.

All the conditions present during a health surveillance event should be recorded. This will include reasons for the event, symptoms reported, examination findings and diagnoses. A problem may arise, however, with regard to the volume of information that would have to be recorded and that might be required to satisfy the epidemiologist. The cost of storing information is also likely to be proportional to the volume to be stored. The temptation is, therefore, to store only as much information as may be required for specific purposes. Having in mind the possible needs of the epidemiologist of the

future, the choices become difficult. One possible compromise is to store all abnormal health findings while neglecting all findings considered normal or falling within a normal range. A system of periodic audits of all examination or special investigation findings must then be introduced as an integral part or function of the Registry. Similarly, an individual not included on the annual summary must be assumed not to have been seen by the medical or health staff as well as not to have had any complaint or injury. A person with completely negative findings but seen during the year, should be entered with the appropriate explanation e.g., Nil Abnormal Discovered (NAD). The results of all abnormal findings related to any special investigation that may have been carried out should be treated in the same manner.

An annual review of the occupational status of all employees should be provided for as well. This should note changes in the type of work and employment duration. Changes in personal health attributes that may not be reported elsewhere should be recorded and forwarded to the Registry. These include changes in personal lifestyle or self-imposed risks and changes with regard to the employee's family history. The type of information required as shown in Figure 9.

4. Storage of Information

Three main information description areas are envisaged. The first is to contain all the information pertaining to a particular individual - a Discreet Individual History File - from which information can be extracted to compile two types of summary reports namely, a summary of the accumulated health findings, updated annually in the form of an individual or group Health Status Profile; and the other an annual Individual Exposure Summary or group Lifetime Exposure Profile.

The Discreet Individual History File has been based on the example of the Discrete History File used by the National (Radiation) Dose Registry[162]. It will contain all the collected information pertaining to individual workers. It should include all the information listed for modules 1 to 3 (Appendix B) as well as the personal exposure data to be derived from module 4. It should be up-dated annually by adding the information received on the Health Information Summary forms. This file should be stored on microfilm or microfiche at regular intervals as is done by the National (Radiation) Dose Registry.

The main purpose of the Health Status Profile or annual up-date of individual health status data is to provide a basis for health surveillance. Outputs would be designed to reflect early deviations from the baseline established by the first full medical examination. An example of an annual summary is given in Figure 10.

The annual or Lifetime Exposure Profile would provide information about the lifetime occupational history of each worker by selected occupational category and duration of exposure (measured in the most convenient units of time e.g. hours, days, weeks, months). Profiles could also be developed for exposure to selected risks or indicator substances by levels of exposure.

The suggested flow of information between information modules and main information storage areas is shown in Figure 11. Also referred to in Figure 11 are the areas of information falling within the respective jurisdictions of the personnel, the occupational health and safety departments, as well as the types of information considered necessary for health surveillance and epidemiological research.

5. Standards and Codes

Standards and codes play an essential role in the operation of a Registry. In this connection the standards and codes developed by Statistics Canada should be adopted in areas for which they are available. These include, for example, geographic codes and those used to indicate country, province, sex and marital status.

The standards developed for identifying information required to search the Mortality Data Bank are of particular interest. The purpose of these standards is to ensure that needed identifiers are present in a useable form when placed on tapes. Such standardization[163] will affect:

- the kinds of identifying information to be keyed to tape;
- the numbers of characters to be keyed for each identifier;
- the format in which the personal names and place names are entered;
- the manner of coding, where codings are required; and
- the manner in which cross-referencing material is entered in various locations within the sequenced files.

The standard provides for a minimum of ten characters per surname. A larger number of characters can be used. This is shown in the tables providing information about the contents of the Mortality Data Bank, the National Cancer Institute's Registry and the National Radiation Dose Registry. A comparison of the number of characters used for identity purposes in these and other Information Banks appear in Table 20. It may be advisable to allocate a larger number of characters for surnames initially, on the basis that it would be easier to reduce rather than to increase the number of characters, once the system has become established. A tentative proposal with regard to the number of characters to assign to identifying information elements is made in the last column.

To protect the confidentiality of health information and to store the large amounts that may be required, the encoding of information becomes a necessity. To meet this need a simple, three digit Health Events Code, based on the International Classification of Diseases[164], was developed (Appendix C). An attempt was made to adapt the standard ICD code to the needs of occupational groups while ensuring the comparability of health surveillance data with the data stored in other morbidity and mortality data banks. It is, however, much simplified since it reduces a large amount of classifiable information to approximately 190 entities. Excluded from the Health Events Code, e.g. are many infectious diseases not likely to be occupational in origin. Included, on the other hand, are categories related to the reasons for seeking health advice,

symptoms and causes of injuries, intoxications and other diseases such as cancer, which are of particular concern to occupational health surveillance.

Included in the Health Events Code and marked by an asterisk, is a listing of Sentinel Health Events (SHE's) i.e. diseases, disabilities or untimely deaths that, on the basis of reports in the scientific literature, may have an occupation-related origin. The occurrence of SHE's could thus serve as a warning that materials substitution, engineering control, personal protection or medical care may be required[165].

It is expected that the Health Events Code would have the necessary sensitivity to identify and record all conditions of special concern to coal liquefaction workers. With regard to the skin, for example, it should allow for the encoding of the following manifestations:

Burns of occupational origin or burns of unspecified site	949
Pigmentation due to chemical sensitization	709
Contact dermatitis (due to such substances as phenols, caustics, acids, oil, metallics e.g. nickel etc.)	692
Boils, furunculosis	680
Folliculitis	704
Acne (used as of occupational origin)	706
Keratosis	701
Benign Neoplasm - papilloma	216
Malignant neoplasm of skin	173

For the coding of the results of special investigations or special screening procedures that have been carried out in support of medical examinations, a simple, open-ended code can be used to code positive or abnormal findings only if more detailed numerical values are not required.

Another area requiring consideration is the coding of occupations. An available option is the Canadian Classification and Dictionary of Occupations[166], developed and used by Statistics Canada for Census purposes. The classification has four levels providing increasing detail: major groups, minor groups, unit groups and occupational titles. The major group classification is closely associated with industry groups. Coal liquefaction workers, for example, could be classified under Major Groups 81/82, minor groups 816/817, unit groups 8160 to 8179 and a large number of occupations. With this system persons in the same industry may be grouped even if the tasks they perform are similar to those in other industries. The system would also group persons even if their exposures were dissimilar. This would amount to a misclassification in the epidemiological sense and would tend to obscure associations between disease and exposure[167] as identified by occupation.

The epidemiologist, however, is interested in grouping occupations according to the chemicals or other agents to which exposure may occur. In the case of the coal liquefaction workers, where worker activity can be assessed in relation to a reasonably defined occupational environment, this may not be a critical issue. A more general occupational health surveillance system would, however, require the adoption or formulation of a code similar to the occupation and exposure linkage system developed by Hoar *et al*[168].

Related to standardization is the need for uniformity in the area of computer hardware. Before implementing a system it would be necessary to consider and define the computer needs of the system as well as the desirability of developing guidelines for the acquisition of computer hardware for occupational health related uses in the various coal liquefaction facilities.

6. Confidentiality of Information

Confidentiality of information held in data banks is governed by the provisions of the Access to Information Act. Under this legislation the individual is specifically protected against the unwarranted release of personal information (as defined in Section 3 of the Act). At the federal level, permission to operate an information bank is also required from the Treasury Board and a description of the aims of the data bank and the types of information to be collected are published in the Index of Federal Information Banks.

The operation of a databank at federal level should in addition be in accordance with the guidelines established by HWC with regard to the handling of confidential material. In general, access is controlled on a need-to-know basis and access to information by any one else is not permitted. Confidentiality of information can be further protected by the use of encoded material, scrambling of Social Insurance Numbers and computer password-logic.

The confidentiality of information contained in the Mortality Data Bank operated by Statistics Canada is strictly protected by the provisions of the Statistics Act.

7. Need for Follow-up Procedures

Because of the long latent periods that may be experienced before low intensity hazard exposure effects may become manifest, records need to be retained for long periods of time. It has been suggested, for example, that industries should retain health surveillance records for periods of 20 to 30 years. The period may well have to be in excess of 50 years because follow-up activities should be carried over into the employee's retirement. Record collection systems therefore need to be adapted to the needs of long-term follow-up surveillance. Efforts are also required to promote worker participation in providing information during periodic follow-up surveys or enquiries that may become necessary.

8. Potential Outputs

Using the information stored in a Worker Registry it would be possible to produce regular periodic reports relating to worker health and safety. These reports are expected to contain statistical information (numbers of employees, numbers of medical examinations and other events of a health related nature); descriptive information (changes in plant levels of exposure, trends with regard to symptoms, diseases, etc.) and analytical information (measurement of risk, effectiveness of surveillance activities).

VI Conclusions

1. The major environmental hazards in the working environment of coal liquefaction workers are skin and inhalation exposure to polynuclear aromatic hydrocarbons (PNAs), acute poisoning from toxic gases such as carbon monoxide and hydrogen sulphide, asphyxiation from oxygen-deficient atmospheres during maintenance in confined spaces, fire, explosion, thermal burns, noise, coal and catalyst dusts.

2. The most difficult problem to control is exposure to PNAs, chemical carcinogens and mutagens, which occur as by-products of all coal liquefaction processes. In addition to a careful program of personal protective measures, routine surveillance of equipment for fugitive emissions with real-time instruments and of tools and surfaces for PNA contamination with UV detectors are required.

3. The workers most exposed in coal liquefaction facilities appear to be maintenance employees and laboratory workers. Workers contracted from outside agencies may be heavily exposed and less aware of the hazards.

4. Health hazard and safety control measures at the Canadian operations examined appeared to be adequate at the current level of activity although protective measures are not uniform and there is a general lack of written health and safety directives. Written procedures would be helpful in relation to skin contamination and in training of new employees. More emphasis needs to be placed also on the availability of safety showers, eye wash stations, fire blankets, first aid kits, safety officers and safety committees, emergency equipment and procedures. Standardization of safety practices and procedures at national level will be useful.

5. During air contamination surveys at BC Research (Vancouver), Sandwell Beak Research Group (Mississauga) and CANMET (Ottawa) coal liquefaction facilities, 1983, concentrations of coal tar pitch volatiles exceeded threshold limit values for short periods, indicating potentially significant exposure to airborne PNAs. As an initial step, measurements of coal tar pitch volatiles and selected PNA indicator compounds should be made at all Canadian experimental facilities and be recorded on employee exposure record. Operations examined should include maintenance procedures.

6. Routine industrial hygiene surveillance has not been implemented at any of the current Canadian research establishments. In addition, the workers at only two facilities benefit from ongoing medical surveillance. Comprehensive industrial hygiene and medical surveillance programs need to be promoted at all Canadian facilities.

7. The collection of information relating to the working environment and worker health forms an integral part of a health surveillance program. When using such information in the epidemiological sense it may be possible to identify risks, quantify the risks associated with particular work exposures and assist in the longer-term evaluation of the effectiveness of control procedures.

8. Despite the many advances made with respect to engineering and medical control technologies, significant short and longer-term health risks remain. Because of the long latent periods that may be experienced before low intensity hazard exposure effects may become manifest, health surveillance (including the maintenance of a data base) will be required for long periods of time. The development of a national register of coal liquefaction workers would facilitate this longer-term surveillance, as well as deal with problems of worker mobility and those related to the small working populations currently scattered across Canada.

9. Industrial hygiene, medical and safety personnel need to be involved during the planning phases of future Pilot and Commercial scale operations i.e. before construction begins. All documents and drawings should be reviewed by Health and Safety Professionals to identify health and safety hazards and to make recommendations for their control. Such a review should become part of an ongoing review process which will be continued from the pre-construction phase, through start-up, and the duration of the plant's cycle of operations.

10. Many investigations have been made in relation to existing or proposed pilot and commercial scale coal conversion facilities in the United States, to identify and quantify emissions, to evaluate hazards, to develop better source controls, personal protective devices and monitoring instrumentation. This information base should be studied and extended, through further research as required, in relation to proposed Canadian developments. Toxicity and biological activity profiles should be developed in connection with the products of all Canadian processes.

VII Recommendations

A. Because of the special nature of the hazards to which workers are exposed in Canadian coal liquefaction operations, health surveillance of all workers should be actively promoted and, where appropriate, uniform guidelines for a health surveillance program should be developed at the national level. A health surveillance program should include:

1. A medical surveillance program for all exposed employees in coal liquefaction operations and associated analytical laboratories, as well as contract/ maintenance workers who have repeated opportunities for exposure to polynuclear aromatic hydrocarbons. The program should include preplacement and periodic medical examinations supported by special investigations and selected laboratory tests, with emphasis on the skin, lungs, kidneys and liver. Health assessments of all workers should be performed at least annually. Emergency medical and first-aid services should be available.

2. An industrial hygiene control and exposure monitoring program with emphasis on the development and adoption of guidelines for engineering controls, personal protective equipment and exposure monitoring. Written procedures and safety data-sheets pertaining to all chemical substances should be available. Monitoring should include periodic measurements of coal tar pitch colatiles (CTPV) and selected PNA indicator compounds in addition to the routine surveillance of toxic gases. Maintenance workers should be included in this program.

3. Development of a record system or data base for the maintenance of personal identifying information, work and health histories and environmental and personal monitoring information. Information should be collected, stored and analyzed. Adequate provision must be made to ensure confidentiality.

B. A National Coal Liquefaction Worker Registry should be established to facilitate the long-term follow-up of coal liquefaction workers and to ensure the comparability of information to be collected in connection with the various small and scattered coal liquefaction worker populations in Canada. The Registry could, when appropriate, be extended to include all present and future workers involved in the product of new synthetic fuels.

C. It is recommended that the federal government (Health and Welfare Canada and Energy, Mines and Resources) undertake a demonstration project, in connection with the workers falling within its jurisdiction, to further promote comprehensive health surveillance of coal liquefaction workers as well as the development of a National Registry. An Advisory Committee, composed of experts in the field and representatives of all participants, should be appointed to advise on all matters relating to the health surveillance system, as well as the promotion of exchanges of information with other coal liquefaction health surveillance programs in Canada and the United States.

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Appendix A
Guidelines for Industrial Hygiene Control Measures and Exposure Monitoring in Coal Liquefaction Facilities

1. Engineering Controls

a) Engineering designs should be reviewed and supported by industrial health and safety professionals. The review should include the problems of startup, normal operation, shutdown, emergency and maintenance.

b) Emphasis should be placed on the integrity of process containment, equipment reliability and limiting the need for worker exposure during operation and maintenance.

c) Consideration should be given to minimizing the effects of erosion-corrosion instrument failure, seal and valve failure, process material sampling systems, coal slurry coking or solidifying, layout, redundancy and fail-safe design.

d) Equipment requiring maintenance should be isolated from the process stream and flushed and purged to remove residual materials.

e) Sampling systems should be designed to remove flammable or toxic materials from the lines by flushing and purging prior to removal of the sampling bomb.

f) The control room should be designed to provide a safe environment for operating personnel.

g) Noise should be considered during design and minimized by equipment selection, isolation acoustic barriers.

2. Work Practices

a) Safety procedures should be developed for fire and explosion hazards, toxic chemical exposure, confined space entry, etc. and all employees thoroughly instructed in the implementation of those procedures.

b) Operating procedures should be developed for each phase of the operation and should include provision for safe storage of process materials, decontamination of equipment requiring maintenance and decontamination of tools.

c) Emergency fire and medical services procedures should be developed including first aid procedures to deal with the possibility of asphyxiation.

d) Process equipment should be cleaned, maintained and repaired only by properly trained employees under responsible supervision.

e) The accumulation of hazardous materials on work surfaces, equipment and structures should be minimized and spills and leaks of hazardous materials should be cleaned up as soon as possible. Employees engaged in cleanup operations should wear suitable respiratory protection and protective clothing.

f) Access to process areas should be restricted to authorized persons. Visitors to a restricted area should be informed of potential hazards, emergency procedures and provided with protective clothing.

3. Employee Training

All employees should receive training concerning the occupational exposure hazards associated with coal liquefaction. Such training should also be extended to outside contractors who may service equipment.

Subjects which should be included in a training program are:

a) Identification of toxic raw materials and coal liquefaction products and byproducts.

b) Toxic effects, including the possible increased risk of developing cancers.

c) Signs and symptoms of overexposure to hydrogen sulphide, carbon monoxide, other toxic gases, and aerosols.

d) Fire and explosion hazards.

e) Oxygen deficiency hazards.

f) Emergency first-aid treatment for overexposure.

g) Plant layout and emergency evacuation procedures.

h) The use, limits of use, storage, and maintenance of all personal protective clothing and equipment that may be used.

i) Hazards that may arise during materials handling, process sampling, housekeeping, waste disposal, and maintenance.

j) The reasons for and the practice of personal hygiene.

k) A description of the general nature of environmental and medical surveillance procedures and the advantages of the employee in cooperating with such procedures.

4. Personal Hygiene

Skin contact with coal liquefaction process materials is a major hazard in coal liquefaction facilities and must be controlled, in part, by good personal hygiene practices. To encourage such practices adequate facilities for washing, showering and surveillance are required.

a) Change rooms should be provided that are equipped with storage facilities for street clothes and separate storage facilities for work garments, protective clothing, work boots,

hard hats, and other safety equipment. Employees working in process areas should shower and shampoo at the end of each workshift. A separate change area for removal and disposal of contaminated clothing, with an exit to showers, should be provided. The exit from the shower area should open into a clean change area. Employers should instruct employees working in process areas to wear clean work clothing daily and to remove all protective clothing at the completion of the workshift. Closed, labelled containers should be provided for contaminated clothing that is to be dry cleaned, laundered, or discarded.

b) Lunchroom facilities should have positive-pressure filtered air supply and should be readily accessible to employees working in process areas. Employees should be instructed to remove hardhats, boots, gloves, contaminated clothing and other protective equipment before entering the lunchrooms, and handwashing facilities should be provided near lunchroom entrances.

c) The following activities should be discouraged in process areas: carrying, consuming, or dispensing food and beverages; using tobacco products and chewing gum; and applying cosmetics.

d) Washroom facilities, eyewash fountains, and emergency showers should be readily accessible from all areas where hazardous materials may contact the skin or eyes. Employees should be encouraged to wash their hands before eating, drinking, smoking or using toilet facilities, and as necessary during the workshift to remove contamination. Employers should instruct employees not to use organic solvents for removing contamination from the skin, because these chemicals may enhance dermal absorption of hazardous materials and are themselves hazardous. Instead, the use of waterless hand cleansers should be encouraged.

e) If gross contamination of work clothing occurs during the workshift, the employee should wash the affected areas and change into clean work clothing at the earliest safe opportunity. The employee should then contact his immediate supervisor, who should document the incident and provide the data for inclusion in the medical and exposure records.

5. Personal Protective Equipment

a) Suitable clothing, gloves, face shields, workshoes and shoe covering should be provided to protect against contact with coal liquid products.

b) Respirators may be required at certain operations, during maintenance and emergencies. They should be selected, used and maintained in accordance with standards of the provincial or federal authority.

c) Hearing protection may be required at some operations, as recommended by the appropriate authority.

d) Adequate training is required for all personal protective equipment.

6. Exposure Monitoring and Records

a) An exposure monitoring program should be developed, based on an inventory of hazardous materials and an initial survey of potential exposures. Data sheets on hazards should be available.

b) Industrial hygiene monitoring should be used to determine whether employee exposure to chemical and physical hazards, such as hydrogen sulphide, carbon monoxide and noise is within established limits.

c) Records should be maintained of disruptions in plant operation by process area, including the frequency and severity of leaks.

d) Periodic area and personal air samples should be collected and analyzed for coal tar pitch volatiles in accordance with procedures acceptable to the appropriate authority. PAH's in a representative bulk sample should be identified: particularly benzo(a)pyrene, pyrene, anthracene, chrysene, phenanthrene, fluoranthrene, benzo(e)pyrene, benzo(a)anthracene.

e) Alarms should be installed for hazards that could immediately threaten life or health such as hydrogen sulphide, carbon monoxide, nitrogen oxides, oxygen deficiency and explosive hazards.

f) Ultraviolet examination of tools, surfaces etc. is recommended for detection of PNA contamination, but should be used for detection of skin contamination, only under medical supervision. Longwave, low intensity blacklight lamps (300 - 800 $\mu W/cm^2$; 356 nm) for surface contamination detection are satisfactory.

g) Records should be kept for each employee detailing his job classifications, plant location codes and to the extent practical, time spent on each job.

h) Real-time indicating instruments for hydrocarbons, carbon monoxide, hydrogen sulphide or other PNA indicators should be used routinely for the detection and control of fugitive emissions.

Appendix B
Listing of Types of Information Required for Health Surveillance Purposes

A. Employee Identity

Surname
Former Surname(s) if any
First Given Name
Second and Other Given Names
Usual Name or Nickname
Sex
Birth Date (year, month, day)
Birthplace (City, Province, Country)
Marital Status

Father's Surname
Father's First Given Name
Father's Second Given Name
Mother's Maiden Name

Social Insurance Number
Health Insurance Number

Place of Residence - Complete Address and Telephone Number

Name, Address and Telephone Number of Person to contact in an Emergency

Name, Address and Telephone Number of Person Who will always know Forwarding Address

Registry Number

B. Occupational History

1. Current Work Status in Industry Participating in Registry:

Name of Employing Industry/Agency/Firm
Type of Industry
Province of Employment
Place of Employment
Occupation
Job Identification (Title)
Employee Number
Job Activities
Work Area(s)
Date Work Begun (year, month, day)
Date Work Ended (year, month, day)

2. Other and Previous Work Experience (From First to Most Recent):

Type of Industry and Location
Job Title
Province of Employment
Place of Employment
Date Work Begun (year, month, day)
Date Work Ended (year, month, day)
Job Activities
Special Hazards (dusts, chemicals, radiation, noise)
Estimates of Severity (Light, Moderately Heavy, Heavy)

3. Duration of Time at Work

Number of hours, days, weeks, months worked in year
Number of hours, days, weeks, months worked in year in specific areas

4. Absences from Work

Date Absence Began (year, month, day)
Date of Return to Work (year, month, day)
Reason for Absence: Leave
Illness
Accident, if so Place of Occurrence
Activity at time of Occurrence

5. Leaving Employment or Change from Coal Liquefaction Work

Date Previous Work Ended (year, month, day)
New Work Location (in same employment)

Date employment began (year, month, day)
New Job Title
New Work activities
Special Hazards

Name of New Employer (if changing work location)
Address of New Employer - Province, City/Place
Type of Industry
Forwarding Home Address of Employee
(complete with postal code)

Retirement - Date (year, month, day)
Complete Forwarding Address
Last Known Alive Year
If Known Dead - Date and Place (Province)

C. Personal Health Information

1. Family History

Illness in Family (Parents, Brothers, Sisters, Spouse, Children):
Diabetes
Tuberculosis
Cancer
Heart Disease
High Blood Pressure
Stroke
Other

Information re Working Spouse
Type of Work
When Started

Information re: Children
Sex
Birthdates
Health Status (including birth defects)

Information re Interrupted Pregnancies
Miscarriages
Date(s)

2. Personal History

Information re: Personal Illnesses provided by YES or NO Responses (Including Assessment by Reviewing Health Personnel)

Epilepsy/Loss of consciousness
Frequent Headaches
Ear, Nose and Throat Disease
Lung Disease
Asthma
Persistent Cough
Tuberculosis
Pneumonia
Heart Disease
High Blood Pressure
Shortness of Breath
Chest Pain
Stomach, Gall Bladder, Bowel Disorders
Liver Disease/Jaundice
Kidney or Bladder Disorders
Skin Conditions
Allergies, Hay Fever, Hives, Drug Sensitivities
Recent Gain or Loss of Weight
Under Treatment for any Condition (Taking Medicines)

3. Self Imposed Risks

Use of alcohol: Does drink, stopped, never drank
Current Usage: Number of ounces of spirits - per day
Small bottles of beer - per day
Glasses of wine - per day

Drugs for any Social Reasons

Smoking: smokes, stopped, never smoked.
Number of years stopped smoking
Number of cigarettes smoked per day (If stopped - number smoked on average during last five years of smoking)

Hobbies with Exposure to:	Solvents
	Oils, Tars
	Other Chemicals (Identify)
	Dusts (Identify)
	Noise

4. Medical Examination Findings

Information re: Examination Findings with Indication of whether Normal or Abnormal. Clinical Assessment or Diagnoses (positive findings) in Coded Form.

Eyes	Left
	Right
Ears	Left
	Right
Head and Neck:	Nasal Passages
	Oral Cavity
	Throat
Chest and Lungs:	Breasts
	Percussion
	Breath Sounds
Cardiovascular:	Pulse Character, Rhythm, Volume, Apex Within Mid-Clavicular Line
	Arteries and Circulation
	Heart Sounds
Abdomen:	Palpation
	Inguinal Region
	Genitalia
	Rectal Examination
Skin:	
Lymphnodes:	

Skeletal:	Upper, Lower Limbs Spinal Column
Central Nervous System:	Sensory and Motor Function Gait, Co-ordination, Tremors Reflexes - Left - Right

Mental Health

5. Interim Health Assessments

Date (year, month, day)

New Findings:	Symptoms/Conditions reported (Coded) Changes, with dates, in: Work History Self-Imposed Risk History Family History

Special Investigations

6. Consultations Sought by Employee (Includes Health Unit Visits)

Date (year, month, day)
Reason - Counselling, Aftercare, New Symptoms/Conditions, Treatment
Findings - Symptoms/Conditions
- Accidents: Place of Occurrence;
Activity at Time of Occurrence

7. Special Investigations

Results of Special Investigations: Reported as Normal or Abnormal (Standards to be followed where applicable)

Chest X-ray
Electrocardiogram
Pulmonary Function Tests
Audiogram
Height
Weight
Blood Pressure

Urinalysis:	Sugar, Albumen, Microscopic
Haematology:	Haemoglobin Haematocrit RBC WBC Differential
Biochemistry:	SMA 4 SGOT TGO (AST) Creatinine Glucose (fasting or pc) SGPT

Biological Monitoring Tests

Cytology

Tests for Mutagenicity

8. Medical Absences from Work

Date Absence Began (year, month, day)
Date of Return to Work (year, month, day)
Medical Reason for Absence
If Accident, Nature of Injury, Treatment Status, Cause

9. Morbidity Information from Other Sources

Health Insurance Plans	Hospital Separations Visits to Physicians

Cancer Registries

10. Information About Deaths

Date of Occurrence (year, month, day)
Cause
Age of Deceased (Date of Birth)

Place of Occurrence	Province, City/Place Home/Institution

Autopsy Report
Death Registration Number

D. Monitoring Data

Workplace Identification	Site Area
Information re Personal Monitoring	Agent(s) Method(s) Measurement(s) Date (year, month, day) Value(s) Current Annual Value (Accumulated Value)

Environmental (Industrial Hygiene) Monitoring Data:
Agents Measured
(Indicator Pollutants)
Methods, Measurement
Data by Work Area

Information re: Duration of Exposure
Number of days, weeks, months worked in year
Number of days, weeks, months working in specific work areas

E. Supporting Information

Technology in Use

Operating History
- Start-up (with dates, time)
- Shut-down (with dates, time)
- Malfunctions/Accidents (with dates, duration)
- Process changes (specify with dates)

Product Information

Process Stream Monitoring Data

Materials Inventory - Data Sheets

Industrial and Environmental Monitoring
- Analytical Methods
- Equipment

Codes
- Health Surveillance
- Accidents
- Industry
- Work Activity Classification

Appendix C
Health Events Code - A Code for the Classification of Symptoms, Diseases and Certain Health Events

I Infectious and Parasitic Diseases

001 All infectious and parasitic diseases

Intestinal infectious diseases
Other forms of tuberculosis
Zoonotic and other bacterial diseases
Poliomyelitis and other non-arthropod-borne viral diseases of central nervous system
Viral diseases accompanied by exanthem
Arthropod-borne viral diseases
Other diseases due to viruses and chlamydiae
Rickettsioses and other arthropod-borne diseases
Syphilis and other venereal diseases
Other spirochaetal diseases
Mycoses
Helminthiases
Other infections and parasitic diseases
Late effects of parasitic diseases

011 Pulmonary Tuberculosis*
020 Plague*
021 Tularemia*
022 Anthrax*
023 Brucellosis*
037 Tetanus*
056 Rubella*
070 Hepatitis*
071 Rabies*
073 Ornithosis*

II Neoplasms

140 Malignant neoplasm of lip, oral cavity and pharynx
Malignant neoplasm of lip, tongue, major salivary glands, gum, mouth, oro- naso- and hypo pharynx, other ill-defined

150 Malignant neoplasm of digestive organs and peritoneum
Malignant neoplasm of oesophagus, stomach, intestines, colon, rectum, liver and intrahepatic bile ducts, gallbladder, pancreas, retroperitoneum and peritoneum, other ill-defined

155 Haemangiosarcoma of the Liver*

158 Mesothelioma of the Peritoneum*

160 Malignant Neoplasm of Nasal Cavities* and of respiratory and intrathoracic organs (excluding trachea bronchus and lung)
Malignant neoplasm of nasal cavities middle ear, sinuses, pleura, thymus, heart, mediastinum, other ill-defined

161 Malignant Neoplasm of the Larynx*

162 Malignant Neoplasm of Trachea, Bronchus and Lung*

163 Mesothelioma of the Pleura*

170 Malignant Neoplasm of Bone*

171 Malignant neoplasm of connective and other soft tissue

172 Malignant melanoma of skin

173 Other malignant neoplasm of skin

174 Malignant neoplasm of breast

179 Malignant neoplasm of genitourinary organs
Malignant neoplasm of uterus, cervix uteri, placenta, ovary and adnexa, prostate, testis, penis, bladder, kidney and other unspecified

187 Malignant Neoplasm of Scrotum*

188 Malignant Neoplasm of Bladder*

189 Malignant Neoplasm of Kidney and Other and Unspecificed Urinary Organs*

190 Malignant neoplasm of other sites
Malignant neoplasm of eye, thyroid gland, other endocrine glands, secondary neoplasm and without specification of site

191 Malignant neoplasm of the brain and unspecified parts of the nervous system

200 Malignant neoplasm of lymphatic and haematopoietic tissue
Lymphosarcoma, reticulosarcoma, Hodgkin's disease, Multiple myeloma,

204 Lymphoid Leukaemia*

205 Meloid Leukaemia*

207 Erthroleukaemia*

210 Benign neoplasms (excluding skin)

216 Benign neoplasm of skin

230 Carcinoma *in situ*
Digestive organs, breast, genitourinary, respiratory system, and other

232 Carcinoma *in situ* of skin

235 Neoplasms of uncertain behaviour and of unspecified nature

III Endocrine Nutritional and Metabolic Diseases and Immunity Disorders

240 Diseases of thyroid and other endocrine glands
Goiter, thyrotoxicosis, hypothyroidism, throiditis, diabetes mellitis disorders of pancreatic secretion and of parathyroid gland, pituitary, thymus, adrenal glands, ovarian and testicular dysfunction, other

260 Nutritional deficiencies

270 Other metabolic disorders
Disorders of amino-acid, carbohydrate, lipoid and plasma protein metabolism, gout, obesity, other

279 Disorders involving the immune mechanism

IV Diseases of Blood and Blood-Forming Organs

280 Diseases of blood and blood-forming organs
Anaemias, coagulation and other defects

283 Haemolytic Anaemia, Non-autoimmune*

284 Aplastic Anaemia*

288 Agranulocytosis or Neutropaenia*

289 Methaemoglobinaemia*

V Mental Disorders

290 Psychoses, neuroses and personality disorders (not elsewhere stated)

303 Alcohol dependence syndrome

304 Drug dependence syndrome

308 Acute reaction to stress

317 Mental retardation

VI Diseases of the Nervous System and Sense Organs

320 Inflammatory diseases of the central nervous system
Meningitis, encephalitis, abscess, thrombophlebitis of sinuses

323 Toxic Encephalitis*

330 Hereditary and degenerative diseases of the central nervous system
Cerebral degenerations, extrapyramidal and spinocerebellar disease, other

332 Parkinson's Disease (secondary)

334 Cerebellar Ataxia*

340 Other disorders of the central nervous system
Multiple sclerosis, paralytic syndromes, epilepsy, migraine, other and unspecified

350 Disorders of the peripheral nervous system

357 Inflammatory and Toxic Neuropathy*

360 Disorders of the eye and adnexa

366 Cataract*

380 Diseases of ear and mastoid process

388 Noise Effects on Inner Ear*

VII Diseases of the Circulatory System

390 Acute rheumatic fever and Chronic rheumatic heart disease

401 Hypertensive disease

410 Ischaemic heart disease

415 Diseases of pulmonary circulation

420 Other forms of heart disease
pericarditis, endocarditis, dysrhythmias, heart failure

430 Cerebrovascular disease

440 Disease of arteries, arterioles, capillaries, veins, lymphatics and other diseases of circulatory system
Arteriosclerosis, aneurysm, embolism and thrombosis, gangrene, varicose veins, other

443 Raynaud's Phenomenon (Secondary)*

VIII Diseases of the Respiratory System

460 Acute respiratory infections
Commond cold, sinusitis, tonsilitis, tracheitis, bronchitis, other

470 Other diseases of upper respiratory tract
Septal deviation, polyps, pharyngitis, chronis sinusitis, chronic disease of tonsils and adenoids, other

480 Pneumonia and influenza

490 Chronic obstructive pulmonary disease and allied conditions
Chronic bronchitis, emphysema, asthma

493 Extrinsic Asthma*

495 Extrinsic Allergic Alveolitis*

500 Coalworker's Pneumoconioses*

501 Asbestosis*

502 Silicosis,* Talcosis*

503 Chronic Beryllium Disease of the Lung*

504 Byssinosis*

506 Acute Bronchitis, Pneumoconiosis and Pulmonary Oedema due to Fumes and Vapours*

508 Respiratory conditions due to other and unspecified external agents

510 Other diseases of respiratory system
Pleurisy, pneumothorax, abscess, congestion, postinflammatory pulmonary fibrosis, empyema, other

IX Diseases of the Digestive System

520 Diseases of oral cavity, salivary glands and jaws

530 Diseases of oesophagus, stomach and duodenum
Ulcer, gastritis, disorders of function, other

540 Appendicitis

550 Hernia of abdominal cavity

555 Noninfective enteritis and colitis

560 Other diseases of intestines and peritoneum
Intestinal obstruction, peritonitis, other

570 Other diseases of digestive system
Acute and subacute necrosis of liver, chronic liver disease and cirrhosis, disorders of gallbladder, diseases of pancreas, gastrointestinal haemorrhage, other.

573 Toxic Hepatitis*

X Diseases of the Genitourinary System

580 Nephritis, nephrotic syndrome and nephrosis
Glomerulonephritis, renal failure

584 Acute or Chronic Renal Failure*

590 Other diseases of urinary system
Infections of kidney, hydronephrosis, calculus of kidney and ureter, Cystitis, disorders of urethra and urinary tract

600 Disease of male genital organs

606 Infertility (male)*

610 Disorders of breast

614 Inflammatory disease of female pelvic organs, other diseases of female genital tract
Inflammatory disorders, endometriosis, prolapse, disorders of menstruation and menopause, other

XI Complications of Pregnancy, Childbirth and the Puerperium

630 Pregnancy with abortive outcome
Hydratidiform mole, ectopic pregnancy, induced abortion, other

634 Spontaneous abortion

640 Complications mainly related to pregnancy

650 Normal delivery

651 Other indications for care in pregnancy, labour and delivery. Complications occurring mainly in the course of labour and delivery. Complications of the puerperium

XII Diseases of the Skin and Subcutaneous Tissue

680 Infections of skin and subcutaneous tissue
Carbuncle, furuncle, cellulitis, impetigo, other

690 Other inflammatory conditions and diseases of skin and subcutaneous tissue
Erythematosquamous dermatosis, atopic dermatitis and related conditions, dermatitis due to substances taken internally, bullous dermatoses, psoriasis, lichen, pruritis, corns callosities, other dermatoses, diseases of nail and subaceous glands, other

692 Contact and Allergic Dermatitis* (solvents, phenol, caustics, Ni., Cr. etc.)

695 Erythematous conditions

701 Other hypertrophic and atrophic conditions of skin (Keratosis)

704 Diseases of hair and hair follicles

706 Acne (Occupational origen)

708 Urticaria

709 Abnormal Pigmentation (Occupational origen)

XIII Diseases of the Musculoskeletal System and Connective Tissue

710 Arthropathies and related disorders
Diffuse diseases of connective tissue, rheumatoid arthritis, other and unspecified disorder of joint

720 Ankylosing spondylitis and other spondylopathies

722 Intervertebral disc disorders

725 Rheumatism and disorders of muscle ligament and fascia

730 Osteopathies, chodropathies and acquired musculo-skeletal deformities
Osteomyelitis, osteitis, other and acquired disorders and deformities of limbs

XIV Congenital Abnormalities

740 All congenital anomalies

XV Certain Conditions Originating in the Perinatal Period

760 Any condition applicable to the newborn

XVI Symptoms, Signs and Ill-Defined Conditions

780 General symptoms

781 Symptoms involving nervous and musculo-skeletal systems

782 Symptoms involving skin

783 Symptoms concerning nutrition, metabolism and development

784 Symptoms involving head and neck (including headache)

785 Symptoms involving cardiovascular system

786 Symptoms involving respiratory system and other chest symptoms

787 Symptoms involving digestive system

788 Symptoms involving urinary system

789 Other symptoms involving abdomen and pelvis

793 Nonspecific abnormal findings on radiological and other examination of body structure

795 Nonspecific abnormal histological and immunological findings

797 Ill-defined and unknown causes of morbidity and mortality

XVI Injury and Poisoning

800 Fractures

830 Dislocation

840 Sprains and strains of joints and adjacent muscle

850 Intracranial injury, excluding those with skull fracture

860 Internal injury of chest, abdomen and pelvis

870 Open wounds, injury to blood vessels

905 Late effects of injuries, poisonings, toxic effects and other external causes

910 Superficial injury

920 Contusions and crushing injury

949 Burns (of occupational origin)

950 Injuries to nerves and spinal cord

960 Poisoning by drugs, medicaments and biological substances

980 Toxic effect of alcohol

981 Toxic effect of petroleum products

982 Toxic effect of solvents other than petroleum-based

983 Toxic effect of corrosive aromatics, acids and caustic alkalis

984 Toxic effect of lead and its compounds (including fumes)

985 Toxic effect of other metals

986 Toxic effect of carbon monoxide

987 Toxic effect of other gases, fumes or vapours

988 Toxic effect of noxious substance eaten as food

989 Toxic effect of other substances, chiefly nonmedicinal as to source

990 Effects of radiation, unspecified

991 Effects of reduced temperature

992 Effects of heat and light

993 Effects of air pressure

994 Effects of other external causes

995 Certain adverse effects not elsewhere classified

996 Complications of surgical and medical care not elsewhere classified

Supplementary Classification

V01 Persons with potential health hazards related to communicable diseases

V10 Persons with potential health hazards related to personal and family history

V20 Persons encountering health services in circumstances related to reproduction and development

V40 Persons with a condition influencing their health status
Mental and behavioural problems, problems with special senses and other special functions, postsurgical states, other problems with internal organs limbs etc.

V50 Persons encountering health services for specific procedures and aftercare
Fitting and adjustment of prosthetic or other device, care involving rehabilitation procedures, orthopaedic aftercare, other and unspecified aftercare, donors

V60 Persons encountering health services in other circumstances
Economic circumstances, other family circumstances, other psychsocial circumstances, unavailability of other medical facilities for care

V65 Persons seeking consultation without complaint or sickness

V66 Convalescence

V67 Follow-up examination

V68 Encounters for administrative purposes

V70 General medical examination (used for PPM)

V71 Observation and evaluation for suspected condition (used for PEM and IHA)

V72 Special investigations and examinations

V75 Special screening for infectious diseases

V76 Special screening for malignant neoplasms

V78 Special screening for disorders of blood and blood-forming organs

V82 Special screening for other conditions

PPM Preplacement Medical Examination (V70)

PEM Periodic Medical Examination (V71)

IHA Interim Health Assessment (V71)

CON Health Consultation (Health Unit Visit) (V40 also V67 and V76)

NAD Nil Abnormal Discovered

NYD Not Yet Diagnosed

NSM Never Smoked

QSM Stopped Smoking

Figure 1. Basic Approaches to Coal Liquefaction

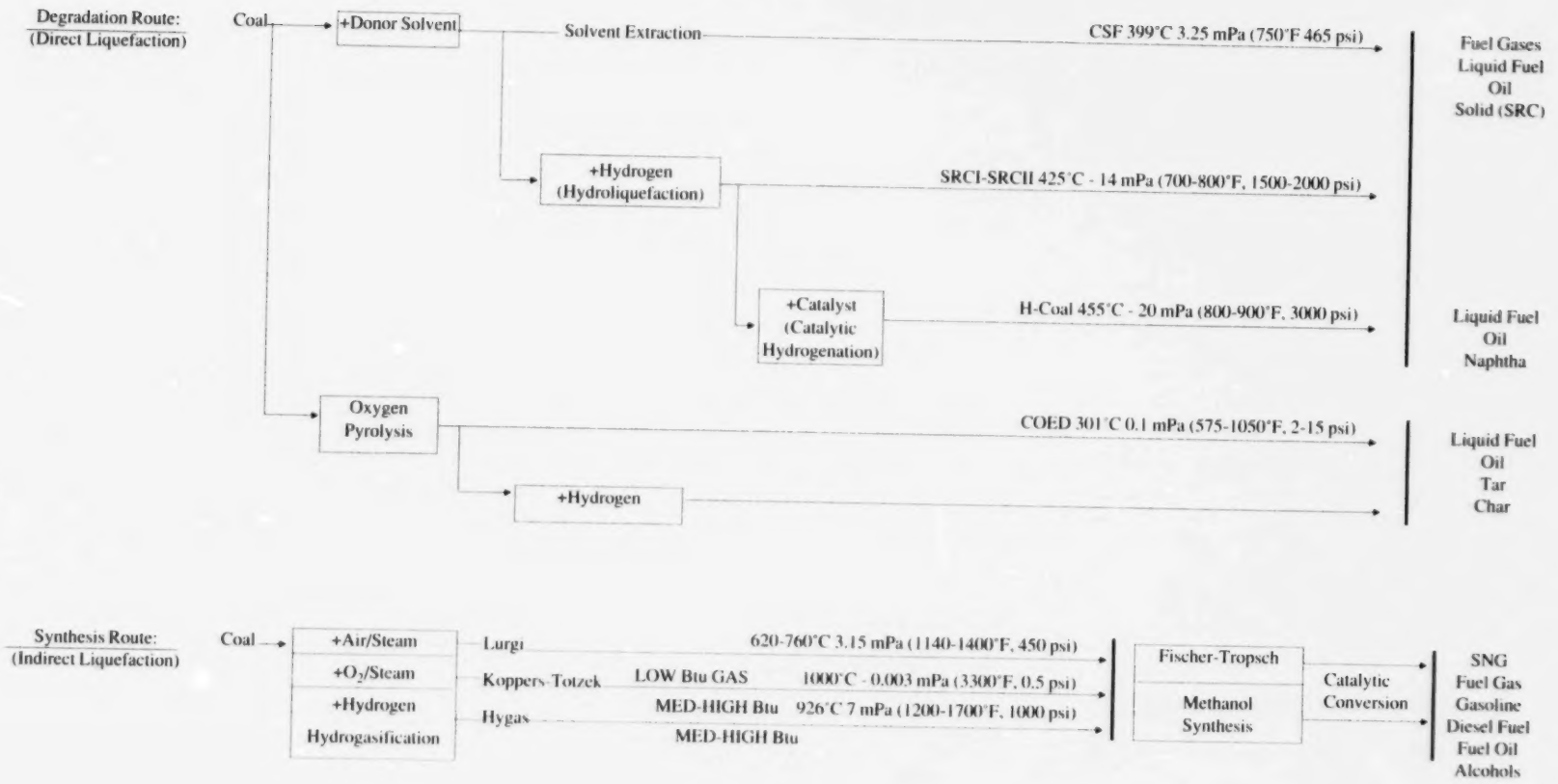

Figure 2. Simplified Block Flow Diagram, CSIRO Flash Pyrolysis Process

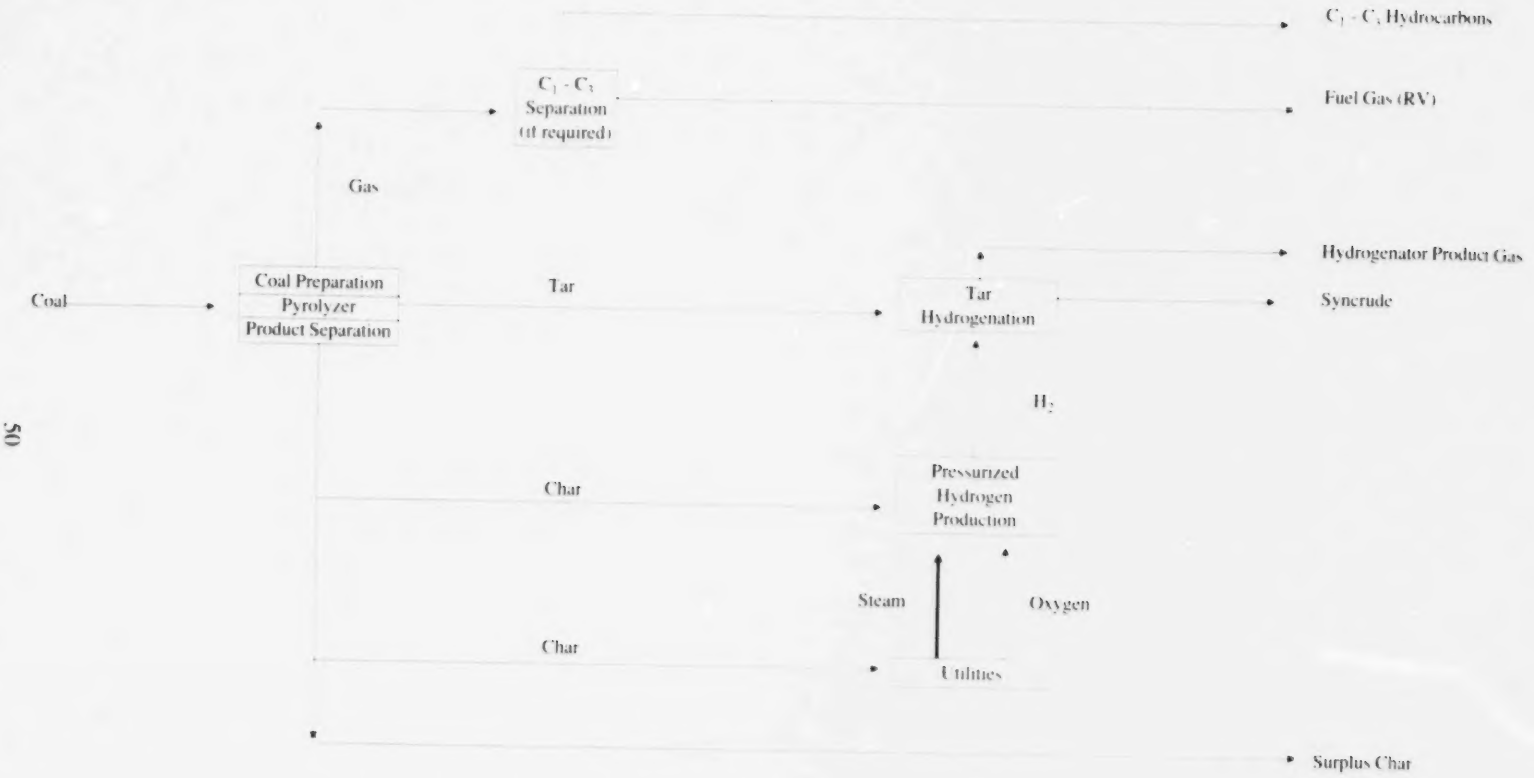

Figure 3. Coal-to-Gas Process Steps

Figure 4. Canmet Continuous Flow Coal Liquefaction Unit

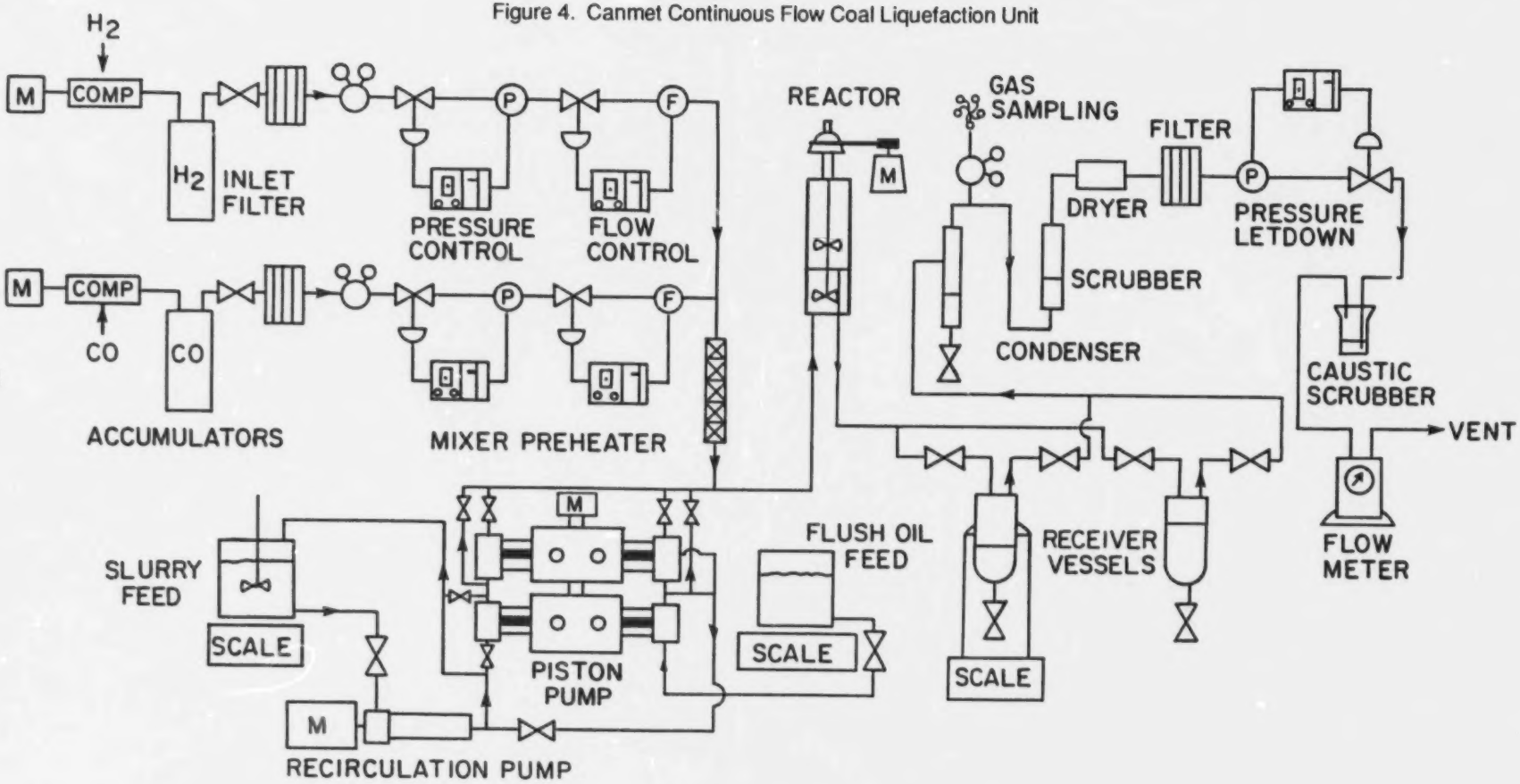

Figure 5. Health Surveillance - Coal Liquefaction Workers

Occupational History

Surname _____ Given Names 1st _____ 2nd _____
Usual Occupation _____ Present Job Title _____ Employee No. _____

The following information is required in the interest of developing a health surveillance program related to your health. Please list all positions held, beginning with your present position.

Type of Industry Location of Industry Job Title... Duration of Employment	From: Year	Month	To: Year	Month		
Main Job Activities Special Hazards Names of Substances (Estimate severity of exposure) - L,M,H*	Dusts	Gases	Chemicals	Radiation	Noise	

Type of Industry Location of Industry Job Title... Duration of Employment	From: Year	Month	To: Year	Month		
Main Job Activities Special Hazards Names of Substances (Estimate severity of exposure) - L,M,H*	Dusts	Gases	Chemicals	Radiation	Noise	

*L = Light Exposure; M = Moderately Heavy Exposure; H = Heavy Exposure

Figure 6. Health Surveillance - Coal Liquefaction Workers

Family History

Confidential

The following information is required to complete your personal health history.

1. Please indicate if any of your blood relatives (father, mother, brothers, sisters) had any of the following diseases:

	Yes	No	Don't Know	If Yes, Who
Diabetes	____	____	_____	_____
Tuberculosis	____	____	_____	_____
Cancer	____	____	_____	_____
Heart Disease	____	____	_____	_____
High Blood Pressure	____	____	_____	_____
Stroke	____	____	_____	_____

2. If you have a spouse, please indicate the kind of work (paid or unpaid) your spouse is doing _____
   Please indicate the last continuous period of work (Years) _____

3. If you have had children, please indicate the sex and birthdate (or age) of all your children, beginning with the eldest. Please indicate also if they have any condition affecting their health. Do they have any handicaps or birth defects. If deceased, please give year and cause of death.

M	F	Birthdate Yr/Mo/Day	Specific Health Conditions	If Deceased - Age and Cause
____	____	_____	_____	_____
____	____	_____	_____	_____
____	____	_____	_____	_____
____	____	_____	_____	_____
____	____	_____	_____	_____
____	____	_____	_____	_____

If you need more space please use back of this form

4. If you are female, have you had pregnancies that resulted in spontaneous miscarriages or stillbirths?
   or
   If you are male, has your present or any previous spouse had pregnancies that resulted in spontaneous miscarriages or stillbirths?

   If yes, how many? _____ and in which years? _____

Date: Year _____ Month _____ Day _____

Figure 7. Selected Listing of Special Risks*

Exposure may occur during work, recreation or the pursuit of hobbies to breathing DUST, SMOKE, FUMES or SPRAYS. Skin contact with various materials and exposure to RADIATION and NOISE may also occur.

For each exposure, please indicate whether this occurred in your job or in a hobby or recreational activity; what years you were exposed; and how many months of the year you were exposed.

Material	Exposed In		Exposed		Frequency:
	Job	Recreation or Hobby	From (year)	To (year)	Months Per Year Exposed
A. DUSTS					
Asbestos					
Coal					
Silica					
Iron ore					
Other (specify)					
B. CHEMICALS					
Herbicides					
Fungicides					
Insecticides					
Crude petroleum					
Shale oil					
Cutting oils					
Diesel fuel					
Tars					
Coal products					
Dyes					
Solvents					
Other (specify)					
C. METALS					
Arsenic					
Chromium					
Nickel					
Cadmium					
Mercury					
Lead					
Other (specify)					

Figure 7. Continued

D. RADIATION
U V Light
X-rays
Radon
Other (specify)

E. OTHER
Exhaust fumes
Plastics mfg.
Rubber mfg.
Battery mfg.
Coke Productn.
Noise
Welding Fumes
Electroplating
Any Other
(specify)

*Adapted from a form used by the Provincial Cancer Hospitals Board, Alberta

Figure 8. Health Status Information Summary

ID#

SIN

INITIALS

BIRTHDATE

PPM

PEM

IHA

CON

SPE

DATE

SYMPTOMS, FINDINGS*

PPM = Pre-placement medical examination
PME = Periodic medical examination
IHA = Interim health assessment
CON = Consultations with occupational health personnel
SPE = Special Investigations

*Reason for health intervention. Symptoms, Findings and Diagnoses should be recorded as coded information

Figure 9. Overview of Changes in Status - Annual Report

Surname _____ Initials _____ Employee Number _____

Social Insurance Number _____ Birthdate Yr ____ Mo ____ Day ____

Address _____ Postal Code _____

CHANGE IN EMPLOYMENT:

Changed Work Activity: Date Yr ____ Mo ____ Day ____

New Job Title: _____ Location_____:

Activities:_____

Leaving for Other Employment: Date Yr ____ Mo ____ Day ____

Name of New Employer _____

Province _____ City/Place _____

Retirement: Date Yr ____ Mo ____ Day _____

Forwarding Address_____

City/Place _____ Prov. _____ Postal Code _____

Change in Family History: _____

_____

Change in Self-Imposed Risks Status: _____

_____

Medical Absences from Work (Dates, Duration, Reasons) _____

_____

Figure 10. Health Status Profile - Annual Update for 19??

ID#

SIN

Initials

Birthdate

No* CONs

No Days Absent

Symptoms, Findings**

* Number of Consultations (contacts) with health personnel including visits to Health Units.

** Coded information relating to symptoms and NEW FINDINGS or CHANGES in previously reported findings since first or base-line examination. Changes in previously reported findings should be qualified by using subsidiary code "p" for progressing and "i" for improving.

Figure 11. Information Modules and Files

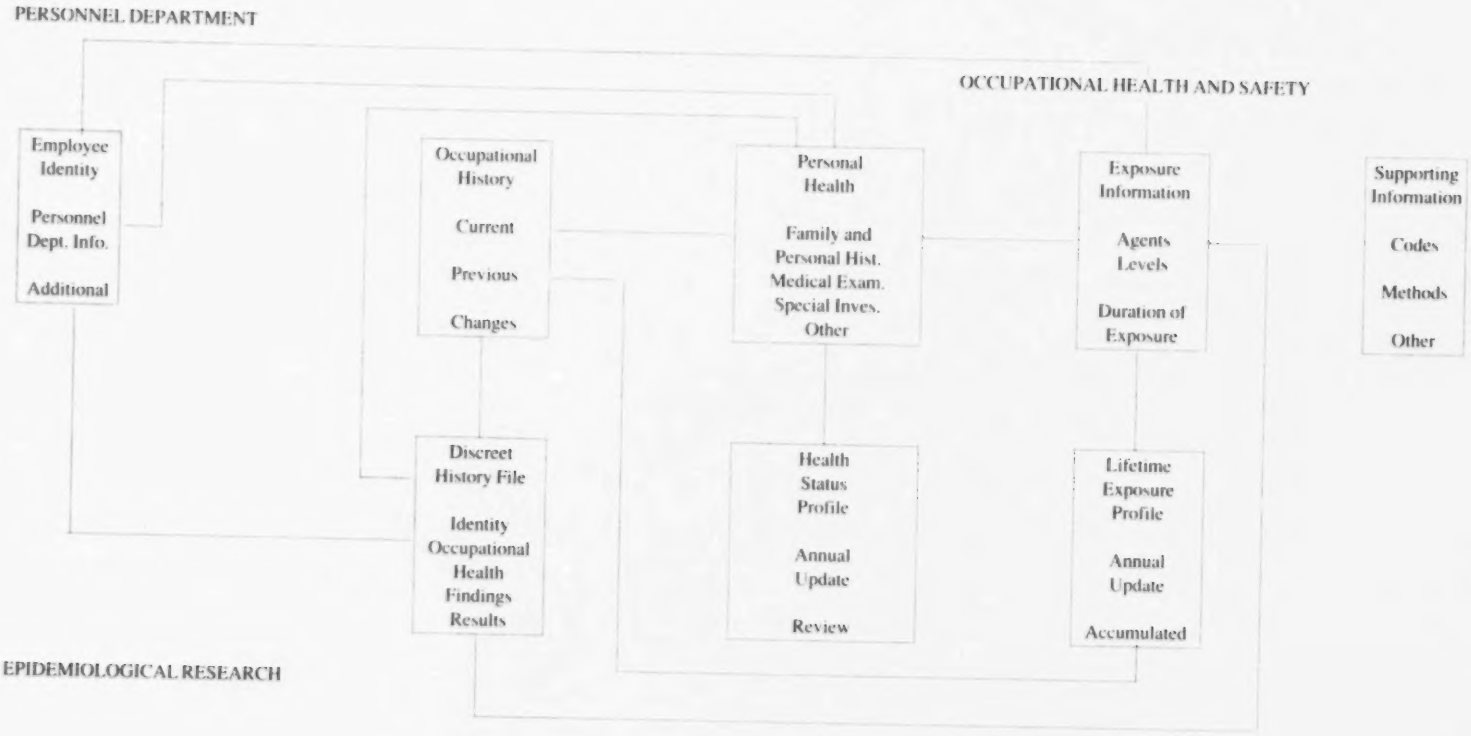

Table 1. Product Slates for Lurgi, Koppers-Totzek and Texaco Gasification Coupled with various Synthesis Processes[16]

Product	*Fischer-Tropsch Synthesis*	*Methanol Synthesis*	*Mobil MTG gasoline synthesis*
Product slate(a) - Lurgi gasification			
Light distillate (gasoline/naphtha)	++	+	++
Middle distillate (diesel oil/turbine fuel)	++	–	–
Heavy distillate (fuel oil)	+	–	–
Liquid petroleum gas	+	–	–
Substitute natural gas	++	++	+
Alcohols	+	++	–
Tar(b)	++	++	++
Product slate - Koppers-Totzek and Texaco gasification			
Light distillate (gasoline/naphtha)	++	–	++
Middle distillate (diesel oil/turbine oil)	++	–	–
Heavy distillate (fuel oil)	+	–	–
Liquid petroleum gas	+	–	++
Substitute natural gas	++	–	–
Alcohols	+	++	–

a Major product, ++; minor product, +; not produced in any significant quantity, –.
b Tar is a product of the Lurgi gasification step, not of the synthesis processes.

Table 2. Hazards at Various Stages of the Coal Liquefaction Process[6]

System/Operation/Process	*Potential Hazards*
Coal Handling and Slurry Preparation System	coal dust, noise, fire, explosion, asphyxia (nitrogen and carbon monoxide), donor solvent, burns
Liquefaction System	phenols, ammonia, tars, thiocyanates, PAH's, carbon monoxide, hydrogen sulphide, hydrocarbons, fires, explosions, burns, high pressures, noise, ash, slag, mineral residue, spent catalyst
Separation System	oils, phenols, hydrogen cyanide, ammonia, hydrogen sulphide, burns, fires
Upgrading and Gas Purification	light hydrocarbons, phenols, ammonia, hydrogen sulphide, carbon dioxide, carbon monoxide, burns, fire, explosion, high pressures
Shift Conversion*	tar, naphtha, hydrogen cyanide, fire, catalyst dust, burns, hot gases (carbon monoxide, hydrogen)
Methanation*	carbon monoxide, methane, nickel carbonyl, spent catalyst dust, fire, burns, methanol
Waste Treatment Facilities	hydrogen cyanide, phenols, ammonia, particulates, hydrocarbon vapours, spent catalyst, sludges, sulphur, thiocyanates

*Indirect Liquefaction

Table 3. Summary of Environmental Information on Classes of Organic Coal Conversion Effluents[15]

Class	*Acute Toxicity*	*Chronic Effects*
Phenols	High	Low
Monoaromatics	Moderate	Low
Polycyclic aromatics	Low	High
Aromatic amines	Moderate	High
Thiophenes	Moderate	High

Table 4. Summary of Toxicity Data Related to the Products of Coal Liquefaction

A: Direct Liquefaction

Toxicity:	
Synthoil	- Low oral, eye and dermal toxicity (acute dermal toxicity-rats; skin corrosion and eye irritation - rabbits) for coal liquids[37].
H-Coal	- Samples moderately toxic - acute LD_{50} 0.5 - 5 g/kg[38]; - No overt skin or eye toxicity[38]; - Unexpected extreme forms of neuro-toxicity associated with dermal exposure to the lighter, minimally carcinogenic materials[38].
SRC I	- Product and dry mineral residue produced relatively little toxicity. Oral LD_{50} in rats 15 g/kg; dermal LD_{50} in rabbits >10 g/kg[39]; wash solvent most toxic[31]; - Relatively low toxicity in inhalation of process and wash solvent materials[39]; - Wet mineral residue, wash solvent and light oil causing severe eye irritation in rabbits, only mild reactions with other materials tested[39]; - Apparent toxicity ranking* SRC I >shale oil >diesel oil >natural petroleum crude oil[31].
SRC II	- Naphtha - some degree of acute toxicity through skin absorption at fairly high dose levels, (unlike EDS and H-Coal naphthas used in test)[40]; - Light, middle and heavy distillates moderately toxic but less than SRC I wash solvent; more than crude shale oil, diesel oil and crude petroleum[31].
COED	- Acute oral LD_{50} for COED syncrude (mice) >5.0 g/kg with low eye and dermal toxicity[37].
Reproductive Toxicity:	
SRC I	- Light oil and wash solvent produced fetal effects only at doses that were maternally toxic and lethal[31]; - Process solvent (a higher boiling fraction) produced prenatal mortality at doses below maternally toxic levels[31].
SRC II	- Light, middle and heavy distillates resulted in slightly greater risk to the fetus than to the mother when administered orally in rats[32].
Mutagenicity:	
Synthoil	- Crude oil strongly mutagenic[40] requiring metabolic activation in Ames test[41] with more than 80% of activity in basic fraction;[42] more potent* than SRC II, COED[42] and petroleum crude[43]; - Basic and neutral fractions also treated with *E. coli* 343/113 Mohn system with positive results[44]; - Basic fractions as well as crude oil highly toxic in *in vitro* mamalian-cell (Chinese hamster ovary) gene mutation assay; a concentration-dependent mutation-induction for the acetone subfraction in the presence of rat liver microsome enzyme activation[45]; - Mutagenicity ranking trend:* synthoil >SRC II[42] >COED[43] >shale oil >natural petroleum[42,43].
H-COAL	- Naphtha and light gas oil samples were found to be non-mutagenic[46]; - Atmospheric still overhead and atmospheric still bottom samples from the fuel oil mode were weakly mutagenic[38]; - The syncrude samples from atmospheric still bottoms, vacuum still overhead and vacuum still bottoms were strongly mutagenic[38]; - The fuel oil samples from vacuum still overhead and vacuum still bottoms were strongly mutagenic[38] and appeared to be more potent than similar syncrude mode samples[33].
SRC I	- Low boiling (light oil) and medium boiling (wash solvent) did not cause transformation in Syrian hamster embryo cell colonies[47]; - A higher boiling fraction produced transformations at a higher rate than with a petroleum crude (Syrian hamster embryo cells)[32]; - The basic fraction had higher activity than the unfractionated material and was higher still with activation[32].

Table 4. Continued

SRC II	- Alkaline and neutral fractions of crude oil more mutagnic than COED oil[33], but less than Synthoil and H-Coal[42]; - Mutagenic activity of crudes increases going from the lower to the higher boiling distillates[48]; - Heavy distillate cut > mutagenic than fuel distillate blend; PAA appeared to play a central role[49]; - Light and middle distillates produced no transformations in *in vitro* cell transformation assays (Syrian hamster embryo cells)[47]; - Higher boiling fractions produced a higher percentage of transformed colonies than did petroleum crudes (Syrian hamster embryo cells); basic fraction strongest[32].
COED	- Basic and neutral fractions of crude oil more mutagenic than natural petroleum crude fractions tested[42,43]; - One neutral fraction ineffective in human leucocyte chromatid aberration assay - without metabolic activation[50]; - Selected fractions of COED syncrude negative in *Drosophila* sex-linked recessive lethal test[50]; - Consistently showed the lowest level of mutagenic activity for all coal derived syncrudes tested[50]; - The Ames test results for the COED syncrude, a hydro-treated pyrolysis oil, showed an average total activity of approx. 500 rev./mg. The SRC II samples were twice as active at greater than 1 000 rev./mg and the Synthoil samples were more than 8 times as active at approx. 4 100 rev./mg[50].
EDS	- Low-boiling naphtha fractions showed little or no mutagenicity[40]; - Higher boiling fractions (gas oils and residues) and the crude oils mutagenic[40].
Carcinogenicity:	
Bergius Process (Catalytic hydrogenation)	- Cutaneous application (1x/wk/15 mo) of centrifuge residue, heavy oil and light oil, produced, in decreasing order, skin carcinometa in mice[34]; - Intra-muscular injections of the same products (1x/mo/3 mo) produced sarcoma[34].
Coal Hydrogenation Plant	- Light oil stream, boiling below 260°C, and its derivatives, produced no tumours when applied to mouse skin (3x/wk/1 yr)[35]; - Higher boiling point streams (middle oil, light oil stream residue, pasting oil and pitch product), highly carcinogenic, the degree increasing as the boiling point increases[35].
Synthoil	- Crude oil moderately carcinogenic when applied to mouse skin (3x/wk/22 wks + 22 wks observation); increasing with increases in the dose applied; data suggested potency* synthoil >shale oil >COED oil[51,52].
H-Coal	- No tumours observed with H-Coal naphtha (syncrude mode)[40]; - Distillates highly carcinogenic to mouse skin; higher boiling materials (gas oils and residues) the most active[38]; - Syncrude and Fuel oil mode fractions more active than EDS and SRC II fractions[40].
EDS	- No tumour initiation with naptha[40]; - Most tumour initiation with higher boiling fractions (Heavy gas oil, vacuum gas oil and residue)[40].
SRC II	- Some degree of dose related carcinogenic potential elicited by heavy distillate but no light distillate, (3x/wk/2 yrs.)[53]; - Most initiating activity with heavy gas oil and other higher boiling distillates[40]; - Relative carcinogenicity: higher boiling distillates >shale oil >crude petroleum >light distillate[53]; - Basic and neutral tar fractions the most active[53]; - The PAH most potent as carcinogens with activity increasing with increasing distillation temperature[48]; in contrast to mutagenicity where N-PAC are more active.
COED	- Crude oil moderately carcinogenic, through 44 wks but less than synthoil and shale crude oils[51,52]; - Data suggest percentage of occurance of cancer is dose dependent[51].

Table 4. Continued

B: Indirect Gasification

I Gasification (Gasifier products)

Toxicity:	
LURGI	- Long-term feeding of up to 5% ash negative in rats[54].
UHD	- Electrostatic precipitator tar samples from the UMD stoic gasifier: - slightly toxic if given orally (mice); moderately toxic by the intra-peritoneal route[55]; - negative for acute skin toxicity (rats)[16]; - do not cause appreciable skin damage and irritation (rabbits)[16] irritation or skin sensitisation in guinea pigs[55]; - moderate and reversible irritation and damage to occular tissues (rabbits)[55].
HYGAS	- Non-volatile organic fraction of Hygas recycle oil caused: - severe occular irritation in rabbits; - markedly delayed skin hypersensitivity in guinea pigs[56].
Reproductive Toxicity:	
LURGI	- Untreated sour water found to be embryotoxic and teratogenic in Xenopus embryo system[57].
UMD	- Aqueous extracts of an electroprecipitator (ESP) tar were embryotoxic and teratogenic in the amphibian system[55]; - Distilled water leachates of bottom ash were both embryotoxic and teratogenic in the amphibian system[55]; - ESP tar caused decreased postnatal survival, cytotoxicity, and some teratogenicity co-incident to the mouse spot test, but there was no evidence of mutation induction[55]; - ESP tar caused transient loss of reproductive capacity in mice. There was a detectable increase in dominant-lethal mutations at all stages in spermatogenesis[55].
Mutagenesis:	
UMD	- Tars from the UMD gasifier: results ranged from non-mutagenic to a few demonstrating high mutagenicity (Ames test with metabolic activation)[55]; - They were also shown to be mutagenic in yeast, but negative for dominant lethal mutations in male mice; one sample also being negative for somatic mutations in the mouse spot test[16]; - Fractionation of ESP tars revealed that mutagenic activity was contributed principally in basic fraction, only secondarily by constituents of the neutral fraction[55]; (cf both basic and neutral fractions in other coal liquids and the relatively little mutagenic activity of natural petroleums coming also from the neutral fraction)[42]; - ESP tars occupy position intermediate to the low-activity petroleum crude oils and the relatively higher-activity liquids, with respect to mutagenic potential. The data suggest a ranking: synthoil >SRC II >UMD ESP tars >COED >shale >petroleum[55].
METC	- Raw gas condensate and samples of gas (process stream aerosol droplets) mutagenic in Ames test with activation[16]; - Mutagenicity associated with neutral and polar, including basic PAH's[16].
HYGAS	- Oils from the Hygas gasifier are weakly mutagenic[16]; - Hygas process streams showed negligible or low mutagenicity but non without activation[58]; - Volatile Hygas fractions (<200°C) demonstrated no significant mutagenicity[58]; - Nonvolatile fractions (>200°C) were moderately mutagenic; with the nonvolatile fractions of recycle oil calculated to have one tenth the mutagenic potency of BaP[58]; - Mutagenicity associated with neutral fraction (20%) and basic fraction (20% - 50%)[16]; - PAA largely responsible for mutagenicity[59] with some due to aza-arenes[16].

Table 4. Continued

Carcinogenicity:	
UMD	- A tar from the UMD gasifier, applied 3x/wk/32 wks, was found to be significantly stronger (30x) as a skin carcinogen in mice than natural petroleums, (despite a demonstrated weak - 232 rev./mg - mutagenic activity)[16]; - Although much less potent than BaP, the UMD tar was still a potent carcinogen[16]; - Positive in the mouse lung adenoma test at the highest of three doses; another tar was weakly positive at a lower dose but demonstrated toxicity at that level[16].
HYGAS	- Nonvolatile organics from a Recycle oil applied 3x/wk/36 wks was shown to be weekly (30x less than BaP) carcinogenic for mouse skin; the unfractionated recycle oil being even less carcinogenic[58]; - A PAA was found to be carcinogenic to neonatal but not to adult mice[58].
II Synthesis (Liquefaction products)	
Toxicity:	
Fischer Tropsch	- Liquids are mainly aliphatic and when processed further would have a toxicity similar to natural petroleum products; - Methanol is produced as one of the end products. Its toxicity in humans is well known. In animal systems methanol has been found to be non-teratogenic and non-mutagenic in a variety of test systems. No information on its carcinogenic potential is available. The toxicity of formaldehyde, as the intermediate in the oxidation of methanol to formate, should also be considered. It is known to be mutagenic in several test systems and to be carcinogenic in animals[16].
Mobil MIG	- Durene (1,2,4,5-tetramethyl benzene), a minor constituent of Mobil gasoline, has only slight acute toxicity[16]; - Zeolite, used as a catalyst, may not have any acute or long-term biotoxicity if similar to the granular Type A[16]; - Methanol may be converted by the Mobil MIG process into gasoline. Its toxicity should be considered as under the Fischer Tropsch process above.
Carcinogenicity:	
Fischer Tropsch	- Fisher Tropsch fractions (Reaction water, light oil and heavy oil) were not carcinogenic when applied to mouse skin; and did not produce sarcomas in rats by intramuscular injection[34]; - Five liquids (synthesis condensate, cracking stock, diesel oil, raw gasoline and used coolant oil) were tested (2x/wk for a life-time in mice and for 25 months in rabbits) and were found to be essentially non-carcinogenic (Hueper, 1955); - The results given by intra-muscular injection of the five liquids (1x/wk/3 wks with repeat after two month interval) were inconclusive.
C. Non Process Specific	
Reproductive Toxicity	
	- Aqueous extracts of complex mixtures were found to be highly embryotoxic and teratogenic to xenopus system with teratogenic concentrations close to LC_{50} values[16]; - Data suggest that polyaromatic, acid and possibly basic fractions are potential teratogens[16]; - Pure compound screening, while limited, showed that the multi-ringed aza-arenes are potential teratogens; PAH's inhibit embryo development; BaP is teratogenic in *in vivo* mammalian tests[16]; - Many trace elements have been studied in whole animal systems and have been shown to be teratogenic; the ranking in animals is in the order: lead = cadmium >selenium >nickel >titanium >molybdenum >arsenic[60].
Carcinogenicity	
	- BaP, DMBA and 3-MCA are known transplacental carcinogens[61]; - a PAA, 6-aminochrysene, is carcinogenic to neonatal mice but not to the adult females[62].

Table 5. Carcinogenic Properties of Individual PNA Compounds and Lowest Effective Tumorigenic (Threshold) Dose[64]

Anthracene	?	3 300 mg/kg	(mice)
Benzo(a)anthracene	+	2 mg/kg	(mice)
Benzo(b)fluoranthene	++	40 mg/kg	(mice)
Benzo(j)fluoranthene	++	288 mg/kg	(mice)
Benzo(k)fluoranthene	–	72 mg/kg	(mice)
Benzo(a)pyrene	+++	0.002 mg/kg	(6 species)
Benzo(e)pyrene	+	140 mg/kg	(2 species)
Benzo(ghi)perylene	–	–	
Chrysene	+	99 mg/kg	(2 species)
Dibenzo(a,h)anthracene	+++	0.006 mg/kg	(5 species)
Fluoranthene	–	–	
Indeno(1,2,3-cd)pyrene	+	72 mg/kg	(mice)
Phenanthrene	?	71 mg/kg	(mice)
Perylene	–	–	
Pyrene	–	10 000 mg/kg	(mice)
Fluorene	?		

Table 6. Chemical Substances in Process Streams, Target Organ Effects* and Medical Aspects

Target Organs	*Chemical Group*	*Health Effects (Acute/Chronic)*	*Medical Aspects*	*Special Investigations*
Skin (and Eyes)	Phenol and phenolics - Cresol - Creosote	Erythema, dermatitis, skin burns, photo-sensitization, keratitis, skin cancer	Elicit history of skin sensitization (also liver and kidney disease)	Patch testing only when photosensiti-zation suspected (not as pre-med examination)
	Crude naphtha aerosols Refined petroleum solvents	Irritation of skin, eyes, upper resp. organs, chapping of skin, burns photosensitization	Emphasize personal hygiene	Urinary phenol excretion
	Residual pitch, tars	Photosensitization, skin cancer	Periodic skin examinations	Skin photography
Respiratory System	Irritant vapours gases including SO_2, NH_3, NOx, etc.	Irritation resp. tract, laryngitis, tracheitis, chronic bronchitis, pneumonia, pulmonary edema, asphyxia	Elicit history of previous respiratory disease and exposure to pollutants	Chest X-Ray Pulmonary function tests
	Particulates: - coal, silica	Bronchitis, pulmonary function changes, pneumoconiosis, silicosis	Periodic assessment	Chest X-Ray and pulmonary function tests
	CTPV**	Lung cancer (long-term exposure)	Periodic assessment	Sputum cytology
Liver and Kidney	Phenolics - cresol	Chronic exposure may cause liver and kidney dysfunction	Previous liver/kidney disease important (also re CNS and skin effects)	Liver function tests e.g. serum bilirubin, SGOT, SGPT Renal function tests
	Carbon disulphide	Liver dysfunction with abnormal serum cholesterol (chronic menstrual)	Also important re cardiovascular disease	CO_2 in breath, blood, urine liver function, ECG
	Naphthylamines	Bladder cancer	Occupational history re: dye, rubber, industries	Urine cytology
Haemopoietic System	Coal naphtha - benzene	Myelotoxicity - anaemia, leukopaenia, throm-bocytopaenia leukemia	Elicit history re previous exposure, blood diseases (also NB for skin and CNS)	Complete blood examination Urinary phenol excretion

Table 6. Continued

Central Nervous System	Cresol Solvents Carbon disulphide	Dizziness, mental confusion, muscular weakness, drowsiness, irritability, insomnia, tremors, polyneuritis	Chronic solvent toxicity effects now recognized, detailed neurological examination	Urinary phenol excretion, hyppuric acid excretion, carbon disulphide in breath, blood, urine
	Carbon monoxide	Poisoning with CNS sequelae, asphyxia	Sensitivity of fetus and pregnant women important	Carboxyhaemoglobin estimation
	Hydrogen sulphide	Upper airway, irritation, CNS depression, paralysis		
Cardiovascular System	Carbon disulphide Carbon monoxide, phenol	Arteriosclerosis with cardiac effects	History and duration of exposure important	Electrocardiographic examination

* Type of effect likely to depend upon duration and severity of exposure.
** Coal Tar Pitch Volatiles are products of the destructive distillation of coal and contain polynuclear aromatic hydrocarbons, generally occurring as vapours in association with or as particulates.

Table 7. The Epidemiologic Basis for Concern about Fossil Fuel and Cancer*

Reference	*Target Population*	*Target Organ(s)*
Pott 1775	English chimney sweeps	Scrotum
Volkmann 1875	Tar and lignite workers	Scrotum
Bell 1876	Shale oil workers	Scrotum
Rehn 1895	Synthetic coal tar dye workers	Bladder
Lueke 1907	Carbon workers	Skin
Henry 1931	Coal tar workers	Bladder
Kuroda 1936	Coal gas workers	Lung
Kennaway 1936	Coal carbonization workers	Lung, Larynx
Henry 1946, 1847[91]	Coal tar and shale oil workers	Scrotum
Kennaway 1947	Street pavers, gas workers, sweeps	Lung
Cruickshank 1950, 52[92-3]	Mineral oil, metal workers	Skin
Doll 1952[94]	Gas retort workers	Lung
Mastromatteo 1955[95]	Workers with cutting oils	Skin
Anon 1958	Coal gas and coke workers	Stomach, Kidney, Pancreas
Bruusgaard 1959	Gas retort workers	Bladder
Sexton 1959[76]	Coal liquefaction workers	Skin
Doll 1965	Gas workers	Lung, Bladder
Kawai 1967[96]	Gas workers	Lung
Mancuso 1967[97]	Workers with betanaphthylamine and benzidine	Bladder, Kidney, Pancreas
Lloyd 1969, 1971[66]	Steel workers, coke producers	Lung
Doll 1972[98]	Gas workers	Lung, Bladder, Scrotum
Redmond 1976[100]	Steel workers, coke producers	Lung, Gastrointestinal, Kidney, Pancreas
Hammond 1976[101]	Roofers	Lung, Gastrointestinal Bladder, Skin
Purde 1979[102]	Shale oil refinery workers	Skin
Gibbs 1979[103]	Reduction plant workers	Lung
Theriault 1979[104]	Oil refinery workers	Brain
Hanis 1979[105]	Oil refinery workers	Stomach, Lung, Oesophagus
Thomas 1980[106]	White males in oil refinery	Skin, Stomach, Brain
Rushton 1981[107]	Oil refinery workers	Gastrointestinal, Nasal sinuses, Oesophagus, Melanoma
Rockette 1983[108]	Aluminum reduction workers	Lymphoid Tissue, Pancreas
Howe 1983[109]	Diesel fume/coal dust exposed	Lung
Mills 1984[110]	Oil/natural gas extractors	Testicle
Hanis 1983[111]	Refinery/chemical plant workers	Kidney
McCraw 1985[112]	Refinery workers	Leukemia

*Expanded from the original listing prepared by Pucknat[90].

Table 8. Cancer Experience and PNA Measurements in Selected Industries

Industry	*Reported Cancers*	*Environmental Measurements*
Gas Production	Lung cancer - 2-4 times greater than general population in UK and almost twice that of urban dwellers in London[94]	BaP: 3 $\mu g/m^3$ average concentration 200 $\mu g/m^3$ above retort houses 2 300 $\mu g/m^3$ in retort fumes[113]
	Bladder cancer - significant excesses[98]	Betanaphthylamine 0.2$\mu g/100m^3$[98] Similar amounts of alphanaphthylamine
	Scrotal cancer	
Coke Ovens	Lung cancer - 2.5 times predicted; almost 5 times increased risk for top-side workers; 10 times increased risk for men working more than 5 years[66]	BaP: 1.2 - 15.9 $\mu g/m^3$ on top-side 0.025 - 1.18 $\mu g/m^3$ off-side at 90-275 meters[114]
	Lung cancer - full time top-side workers with 5 years exposure have almost 11 times predicted risk; 2.5 times for those at side-oven jobs[100]	1.3 - 42.73 $\mu g/m^3$ at top-side with higher values at collecting and other sites 0.0 - 12.1 $\mu g/m^3$ at 100 meters[115]
	Kidney cancer - only among men with exposure at the side-oven[100]	CTPV: 357 - 1670 $\mu g/m^3$ on top of battery 7.2 - 322 $\mu g/m^3$ off batter (cyclohexane soluble)[114]
	Digestive tract cancer - workers employed in non-oven areas[66,100]	
	Pancreatic cancer among non-oven workers[100]	
	Lung cancer - 3 to 10 times the comparison group; increasing with increasing exposure over 200 mg/m^3 months[116]	CTPV: average exposure on top-side 3.15 mg/m^3; on oven-side I, 1.99 mg/m^3; and side-oven II, 0.88 mg/m^3[116]
Roofing and Water Proofing Industry	Lung cancer - among roofers with 20+ years of exposure: SMR 1.59[101]	BaP: 14 $\mu g/m^3$ Roof tarring area; 75 $\mu g/m^3$ Coal-tar-pitch area[101, 113]
	Digestive system cancers (multiple sites) Ratios demonstrate increasing risk with increasing exposure[101]	BaP on mask per 7 hr working day: average values for shovelman 53.0 $\mu g/m^3$; scraper 51.8 $\mu g/m^3$; kettleman 31.0 $\mu g/m^3$[101]
	Bladder and skin[101]	
Coal Liquefaction	Skin cancer - 16 to 37 times that for the general population[76]	BaP: >0.05 $\mu g/m^3$ - with observed peak value of 18 $\mu g/m^3$[117]
	Skin cancer - 3 of 190 workers[78]	

Table 9. Worker Exposure to Airborne Contaminants at Two Coal Liquefaction Pilot Plants

Contaminant	OSHA Health Standards (NIOSH) Recommendations	Donor Solvent/Catalytic Hydrogenation Process						Donor Solvent Process					
		Field Technicians		Maintenance		Lab Technicians		Field Technicians		Maintenance		Lab Technicians	
		No. of Samples	Range (Mean)[d]	No. of Samples	Range (Mean)[d]	No. of Samples	Range (Mean)[d]	No. of Samples	Range (Mean)[d]	No. of Samples	Range (Mean)[d]	No. of Samples	Range (Mean)[d]
Total PNA ($\mu g/m^3$)[a,c]	–	12	0.1-0.3 (0.2)	6	0.02-0.5 (0.2)	3	0.05-0.3 (0.2)	12	3-260 (63)	2	85-130 (108)	3	1.22 (9)
Benzene (ppm)[b]	10 (1)	–	–	–	–	3	0.04	7	0.01-0.02	1	– (<0.02)	3	<0.01
Toluene (ppm)[b]	200 (100)	–	–	–	–	3	0.08	7	0.01-0.1	1	– (0.08)	3	<0.1
Xylene (ppm)[b]	100 (100)	–	–	–	–	3	<0.01	7	0.01-0.04	1	– (0.04)	3	<0.01
Aniline (ppm)[c]	5	15	<0.1	5	<0.1	3	<0.1	12	0.01-0.02	1	– (0.3)	3	<0.02
N,N-Dimethylaniline (ppm)[c]	5	15	<0.08	5	<0.08	3	<0.07	12	<0.01	1	– (0.02)	3	<0.01
2,4-Dimethylaniline (ppm)[c]	–	15	<0.05-0.1	5	<0.08	3	<0.07	12	<0.04	1	– (<0.02)	3	<0.02
p-Nitroaniline (ppm)[c]	1	15	<0.07	5	<0.07	3	<0.06	–	–	–	–	–	–
o-Toluidine (ppm)[c]	5	15	<0.09	5	<0.09	3	0.1	12	<0.02	1	– (<0.02)	3	<0.01
o-Anisidine (ppm)[c]	0.1	15	<0.09	5	<0.1	3	<0.1	12	<0.02	1	– (<0.03)	3	<0.02
p-Anisidine (ppm)[c]	0.1	15	<0.1	5	<0.1	3	<0.1	12	<0.02	1	– (<0.03)	3	<0.02

Table 9. Continued

[a]Sampling was conducted with a 37 mm cassette containing a silver membrane filter sandwiched between two methyl cellulose gaskets backed by 200 mg of Chromosorb 102 in a 1/4-inch diameter glass tube. Analyses were made by gas chromatograph/mass spectrograph and high-pressure liquid chromatography. Sensitivity of the 29 PNA's were within the 1-6 nanogram range. Anthanthrene was the least sensitive at 44 nanograms.

[b]Sampling was by charcoal tube at 100 mL/min with analyses by gas chromatography using the NIOSH standard method P & CAM 127. 30-40 nanograms can be detected in a 20-liter air sample.

[c]Silica gel tubes were used at a sampling rate of 100 mL/min. Analyses were made by gas chromatography using the NIOSH method P & CAM 168. The level of sensitivity ranged from 0.05 ppm for o-anisidine and 2,4-dimethlaniline to 0.2 ppm for p-anisidine.

[d]Less than values (‹) indicate that the compound is present but at concentrations which cannot be accurately quantified. The number given represents the concentration which can be accurately measured based on the sensitivity of the analytical method and the sample size. Where the less than value (<) is given in place of the range, this indicates that all samples were below this concentration.

[e]This total includes 29 PNA's:

Acenaphthalene
Acenaphthene
Acridine
Anthranthrene
Anthracene
Benz(a)anthracene
Benzo(a)fluorene
Benzo(b)fluorene
Benzo(g,h,l)perylene
Benzo(a)pyrene
Benzo(e)pyrene
Carbazole
Chrysene/Triphenylene
Coronene
Dibenz(a,j)acridine
Dibenzanthracene
Dibenz(a,l)carbazole
Dibenzpyrene
Dimethylbenz(a)anthracene
Fluoranthene
Fluorane
Indeno(1,2,3-cd)pyrene
2-Methylnaphthalene
1-Methylnaphalene
Naphthalene
Quinoline
Perylene
Phenanthrene
Pyrene

Table 10. Potential Monitoring Requirements of a Synfuel Industry[129]

Chemical Monitoring	*Physical Monitoring*
Trace metals	Noise (steady state, impact)
Mercury	Stress from heat and cold
Cr(VI)	Temperature
Free silica	Humidity
Total and respirable particulates	
- particle size and particle extract	*Medical Monitoring*
Aliphatic hydrocarbons	
(including cyclohexane)	(Discussed in Section V)
Aromatic hydrocarbons	
(PAHs, PNAs)	
Aromatic amines	
(Naphthylamine, analine, etc.)	
Benzene	
Phenol	
Pyridine	
Methane	
Formaldehyde	
Carbon monoxide	
Hydrogen cyanide	
Ammonia	
Sulphur dioxide	
Hydrogen sulphide	
Mercaptans (RSH etc.)	
Carbonyl sulphide	
Carbon disulphide	
Metal carbonyls	
Arsine	
Nitrogen oxides	
Carbon dioxide	
Heat-exchanger fluid	
(e.g. Dowtherm)	

Table 11. Summary of Qualitative CG/MS Results of Air Sampling at the SBRG Coal Liquefaction Facility - Percent of Total Chromatogram

Compound	*Slurry Area*		*Product Sampling Area*					*Separation Area*			
	1.5 L low-vol	*3,150 L XAD-2 extract*	*1.0 L*[5] *low-vol*	*1.5 L low-vol*	*1.5 L*[2,3] *low-vol*	*3.0 L*[5] *low-vol*	*3,150 L XAD-2 extract*	*1.0 L*[6] *low-vol*	*1.5 L low-vol*	*1.5 L*[4] *low-vol*	*3.0 L*[6] *low-vol*
Analysis #	*4426*	*4586*	*4369*	*4424*	*4425*	*4382*	*4585*	*Q0336*	*4427*	*4428*	*4368*
Aliphatic and Cyclic Hydrocarbons	11.6	4.1	24.6	16.0	5.5	1.9	5.8	3.5	65.9	11.7	0.5
Simple Carbon - Oxygen	0.7	–	0.14	3.3	–	–	–	9.8	3.3	4.0	–
Simple Carbon - Nitrogen	–	0.5	–	–	–	–	–	–	2.4	0.5	–
Halogenated Organics	–	–	.62	–	–	–	–	1.6	–	–	–
Heterocycles	1.2	8.0	.6	–	–	2.0	8.0	2.4	–	–	10.0
Substituted Benzene Compounds	13.5	5.2	23.7	16.1	13.5	26.8	4.5	28.4	13.7	29.3	27.7
Polynuclear Aromatic Hydrocarbons	62.0	79.0	40.7	37.7	46.6	51.9	81.1	2.0	1.6	13.3	9.2
Total	89	96	90.3	70	65.6	82.6	99	47.2	86.9	59.3	58.6

1. Peak area expressed as ion current, meV.
2. CG column used; Superox, 50 metre. All other analysis performed with a DB1 column, 30 metres.
3. Sample taken behind lexan shield.
4. Taken during bottoms removal.
5. Taken during heating with anthracene oil in unit.
6. Taken when separation system not operational.

Note: Columns do not total 100% since background and contaminant peak area contributions are not listed.

Table 12. Results for Sampling at BC Research

Contaminant	*Maximum Concentration*		*Normal Range*		*Permissible Concentration**			
					ACGIH	*B.C.*	*ONT.*	
Polynuclear Aromatics:								
Total	0.6	mg/m^3	<0.1	mg/m^3	0.2	0.2	0.15	mg/m^3
Individual	9	$\mu g/m^3$	<0.1-1	$\mu g/m^3$	-	-	-	
Hydrocarbons:								
Benzene	1.6	ppm	<0.01-0.09	ppm	10	10	10	ppm
Toluene	0.2	ppm	<0.01-0.03	ppm	100	100	100	ppm
Xylene	0.3	ppm	<0.01-0.03	ppm	100	100	100	ppm
p-Cymene	0.2	ppm	<0.01	ppm	-	-	-	
Cumene	<0.01	ppm	<0.01	ppm	50	50	50	ppm
Mesitylene	0.04	ppm	<0.01-0.01	ppm	25	25	25	ppm
Indene	0.05	ppm	<0.01-0.03	ppm	10	10	10	ppm
Tetralin	0.01	ppm	<0.01	ppm	-	-	-	
Biphenyl	<0.01	ppm	<0.01	ppm	0.2	0.2	0.2	ppm
Nitrogen-Containing Aromatics:								
Aniline	0.09	mg/m^3	<0.05	mg/m^3	10	19	8	mg/m^3
Dimethylaniline	<0.05	mg/m^3	<0.05	mg/m^3	25	25	25	mg/m^3
p-Toluidine	<0.05	mg/m^3	<0.05	mg/m^3	22	22	9	mg/m^3
Anisidines	<0.10	mg/m^3	<0.10	mg/m^3	0.5	0.5	0.5	mg/m^3
Pyridine	1.1	ppm	<0.01-0.04	ppm	5	5	5	mg/m^3
Polynuclear Aromatic Amines:								
Quinoline	0.06	mg/m^3	<0.05	mg/m^3	-	-	-	
Indole	0.03	mg/m^3	<0.01	mg/m^3	-	-	-	
Aminobiphenyl	0.05	mg/m^3	<0.01	mg/m^3	0	0	0	
Carbazole	0.04	mg/m^3	<0.01	mg/m^3	-	-	-	
Phenolics:								
Phenol	<1	mg/m^3	<1	mg/m^3	19	19	19	mg/m^3
Cresols	<1	mg/m^3	<1	mg/m^3	22	22	22	mg/m^3
Naphthols	<1	mg/m^3	<1	mg/m^3	-	-	-	
Sulphur-Containing Gases:								
Hydrogen Sulphide	6.2	ppm	<0.01	ppm	10	10	10	ppm
Methyl Mercaptan	0.7	ppm	<0.02	ppm	0.5	3	0.5	ppm
Sulphur Dioxide	<0.03	ppm	<0.03	ppm	2	5	2	pm
Dimethyl Sulphide	2.4	ppm	<0.03	ppm	-	-	-	

*ACGIH: American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values. B.C. Workers' Compensation Board 8-h permissible concentrations. Ontario Ministry of Labour time-weighted average exposure criteria.

Table 13. Results for Sampling at CANMET

Contaminant	*Maximum Concentration*		*Normal Range*		*Permissible Concentration**			
					ACGIH	*B.C.*	*ONT.*	
Polynuclear Aromatics:								
Total	0.1	mg/m^3	<0.1	mg/m^3	0.2	0.2	0.15	mg/m^3
Individual	3	$\mu g/m^3$	<.1-2	$\mu g/m^3$	-	-	-	
Hydrocarbons:								
Benzene	0.04	ppm	<.01-0.02	ppm	10	10	10	ppm
Toluene	0.06	ppm	<0.01	ppm	100	100	100	ppm
Xylene	0.05	ppm	<0.01	ppm	100	100	100	ppm
p-Cymene	<0.01	ppm	<0.01	ppm	-	-	-	
Cumene	<0.01	ppm	<0.01	ppm	50	50	50	ppm
Mesitylene	0.03	ppm	<0.01	ppm	25	25	25	ppm
Indene	0.01	ppm	<0.01	ppm	10	10	10	ppm
Tetralin	<0.01	ppm	<0.01	ppm	-	-	-	
Biphenyl	<0.01	ppm	<0.01	ppm	0.2	0.2	0.2	ppm
Nitrogen-Containing Aromatics								
Aniline	0.06	mg/m^3	<0.05	mg/m^3	10	19	8	mg/m^3
Dimethylaniline	<0.05	mg/m^3	<0.05	mg/m^3	25	25	25	mg/m^3
p-Toluidine	<0.05	mg/m^3	<0.05	mg/m^3	22	22	9	mg/m^3
Anisidines	<0.10	mg/m^3	<0.10	mg/m^3	0.5	0.5	0.5	mg/m^3
Pyridine	1.04	ppm	<0.01-0.03	ppm	5	5	5	mg/m^3
Polynuclear Aromatic Amines:								
Quinoline	<0.05	mg/m^3	<0.05	mg/m^3	-	-	-	
Indole	<0.01	mg/m^3	<0.01	mg/m^3	-	-	-	
Aminobiphenyl	0.02	mg/m^3	<0.01-0.01	mg/m^3	0	0	0	
Carbazole	<0.01	mg/m^3	<0.01	mg/m^3	-	-	-	
Phenolics:								
Phenol	<1	mg/m^3	<1	mg/m^3	19	19	19	mg/m^3
Cresols	<1	mg/m^3	<1	mg/m^3	22	22	22	mg/m^3
Naphthols	<1	mg/m^3	<1	mg/m^3	-	-	-	

*ACGIH: American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values. B.C. Workers' Compensation Board 8-h permissible concentrations. Ontario Ministry of Labour time-weighted average exposure criteria.

Table 14. Composition of Bulk Samples

Hydrocarbon	*Feed Slurry Material*	*Naphtha-Water Mix*	*Product Light Oil*	*Hot Centrifuge Product*
naphthalene	0.71	<0.01	2.16	0.77
acenaphthene	0.39	<0.01	1.13	1.18
bibenzyl	0.33	<0.01	1.13	1.26
dibenzothiophene	0.56	<0.02	0.65	1.21
phenanthrene	8.18	<0.01	2.71	7.21
anthracene	2.53	<0.01	0.35	0.36
carbazole	1.16	<0.01	0.56	1.11
fluoranthene	0.76	<0.01	0.15	0.83
pyrene	5.10	<0.01	0.98	4.02
1,2-benzanthracene	1.55	<0.01	0.12	0.53
chrysene	1.42	<0.01	0.26	1.04
benzanthrone	0.10	<0.01	0.06	0.17
benzo(e)pyrene	0.50	<0.01	0.07	0.31
benzo(a)pyrene	0.70	<0.01	0.07	0.29
perylene	0.26	<0.01	0.03	0.12
1,12-benzoperylene	0.13	<0.01	0.02	0.09

NOTES: Results in % by weight
Samples analyzed by capillary gas liquid chromatography
Not all PAH's were identified

Table 15. Chemical Composition of CLP (154 - 378°C)

Compound	*mg/g Coal Liquid*
n-Octane	0.7
n-Decane	4.3
1-Decene	0.4
n-Dodecane	5.1
n-Tridecane	2.4
n-Tetradecane	15
n-Pentadecane	6.6
n-Hexadecane	8.8
n-Octadecane	9.0
n-Eicosane	4.7
n-Butylcyclohexane	0.3
Total Aliphatics	58
Ethylbenzene	2.2
1,3/1,4-Dimethylbenzene	1.7
1,2-Dimethylbenzene	0.9
1,3,5-Trimethylbenzene	0.9
Isoprophylbenzene	0.3
2-Ethyltoluene	0.5
n-Propylbenzene	0.8
4-Isopropyltoluene	0.3
n-Butylbenzene	0.9
sec-Pentylbenzene	0.1
Total Benzenoids	8.6
Phenol	0.5
2-Methylphenol	0.2
Hydroquinone	0.5
Total Phenols	1.2
Naphthalene	33
Tetralin	17
1-Methylnaphthalene	19
2-Methylanaphthalene	31
Acenaphthylene	0.5
Biphenylene	0.3
Acenaphthene	70
Biphenyl	10
Dimethylnaphthalene(1,2-2,7)	2.7
1,3-Dimethylnaphthalene	23
Dimethylnaphthalene(1,4-2,3)	7.2
Dimethylnaphthalene(1,5-2,6)	7.9
1-Ethylnaphthalene	3.2
2-Ethylnaphthalene	6.8
Fluorene	92
3-Methylbiphenyl	5.6
4-Methylbiphenyl	2.7
Dibenzofuran	20
Xanthene	0.5
Phenanthrene	257
9,10-Dihydrophenanthrene	35
Durene	1.1
9,10-Dihyroanthracene	10.6
1-Methylfluorene	1.5
1-Methylphenathrene	16
Fluoranthene	84
Pyrene	48
1-Phenylnaphthalene	3.3
1,2,3,6,7,8-Hexahydropyrene	1.1
2-Methylanthracene	53
1,2,3,4,5,6,7,8-Octahydro-Anthracene	0.7
Dibenzothiophene	4.1
1,2-Benzofluorene	8.5
Chyrsene	2.6
Benz(a)anthracene	7.1
Total Polynuclear Aromatics	898
Total Compounds Identified	965

Table 16. Comparison* of Industrial Health Programs for Coal Liquefaction Pilot Plants

	Medical Examinations		*Work Clothing*				
Plant	*Subcontractors*	*Company Employees*	*Subcontractors*	*Company Employees*	*Showers*	*Work Assignments for Women*	*Industrial Hyg Monitoring Pr*
A	Annual exams required for personnel who work in regulated areas more than 30 days per year	Annual exams required for personnel who work in regulated areas more than 30 days per year	Outer clothing provided	Outer and under-clothing provided	Mandatory	Restrictions on hiring	In-house progr
B	Same as above except for 90 day provision	Same as above	Outer and under-clothing provided	Same as above	Mandatory	No restrictions	In-house progr
C	Exams provided for all permanent personnel who work in regulated areas		Outer clothing provided; under-clothing provision started, but was dropped		Mandatory	No restrictions	Outside servic
D	Same as above		Outer clothing provided		Mandatory	Restrictions on hiring	Outside servic
E	Same as B above	Annual exams required of all company personnel	Outer clothing provided		Highly recommended	No restrictions on hiring; some non-chemically related restrictions on work practices	In-house progr

*Coal liquefaction pilot plants have dynamic programs; hence, the programs above are subject to change.

Table 17. Detection of and Biological Values for Selected Chemical Substances in Body Fluids[171]

Chemical Agent	*Biological Parameter*	*Biological Material*	*Normal Values*	*Tentative Maximum Permissible Value*
Benzene	phenol	urine	< 20 mg/g creatinine	45.0 mg/g creatinine
	benzene	blood		
	benzene	expired air	< 0.006 ppm	
Toluene	hippuric acid	urine	< 1.5 mg/g creatinine	2.5 mg/g creatinine
	o-cresol	urine	< 0.3 mg/g creatinine	1.0 mg/g creatinine
	toluene	blood		0.1 mg/100 mL during exposure
	toluene	expired air		20.0 ppm during exposure
Phenol	phenol	urine	< 20 mg/g creatinine	300.0 mg/g creatinine
	phenol	saliva		
Several Aromatic amino and nitro compounds	methaemoglobin	blood	< 2.0 %	5.0 %
	diazo- positive metabolites	urine	< 10 mg/g creatinine	
	parent-compound (e.g. benzidine b-naphthylamine)	urine		
Analine	p-aminophenol	urine		10.0 mg/g creatinine
Nitrobenzene	p-aminophenol	urine		5.0 mg/g creatinine
Methanol	methanol	urine	< 2.5 mg/g creatinine	7.0 mg/g creatinine
	formic acid	urine		

Table 10: Suggested Periodicity of Medical Examinations and Special Investigations for Healthy Workers

Personal and Family Health Histories	Every 2 years
Medical Examinations	Every 2 years
Interim Health Assessment	Intervening years
Chest X-ray	Every 4 years
Electrocardiogram	Up to age 59, every 10 years, afterwards, every 5 years
Pulmonary Function	Every 2 - 4 years
Audiogram	Every 2 years
Examination of Urine	Annually
Examination of the Blood	Annually
Blood Chemistry	Annually
Review of Skin Condition	Every 6 months

Table 19. Employee Identity Information Available from Coal Liquefaction Facilities Compared with Information Available in Other Sources

	NS-RFC	*CAN MET*	*ORF*	*SB-RG*	*ARC*	*BCR*	*NRD REG*	*NCI RS*	*DTH CRT*	*MDB*	*CLW* PRO*
Surname**	x	x	x	x	x	x	x	x	x	x	x
Former Surname (if any)							x				x
First Given Name	x	x	x	x	x	x	x	x	x	x	x
Second and Other Given Names	x	x	x	x	x	x	x	x	x	x	x
Usual Name or Nickname											x
Sex	x	x	x	x	x	x	x	x		x	x
Birth Date (yr, mth, day)	x	x	x	x	x	x	x	x	x	x	x
Birth Province or Country				x			x	x	x	x	x
Birth City or Place											x
Father's Surname										x	x
Father's First Given Name							x			I	
Father's Second Given Name										I	
Father's Birth Prov./Country											
Father's Birth City or Place											
Father's Birth Date (or age)											
Mother's Maiden Name							x		x	x	x
Mother's First Given Name										I	
Mother's Second Given Name										I	
Mother's Birth Prov./Country										x	
Mother's Birth City or Place											
Mother's Birth Date (or age)											
Marital Status	x	x			x			x		x	x
Spouse's Birth Surname								x		x	
Spouse's First Given Name										I	
Spouse's Second Given Name										I	
Spouse's Birth Prov./Country											
Spouse's Birth City or Place											
Social Insurance Number	x	x	x	x	x	x	x	x		x+	x
Health Insurance Number				x	x			x			x
Place of Residence	x	x	x	x	x	x		x		x	x

* = Identifying information proposed for Coal Liquefaction Workers
** = Identifying information proposed for genetic studies
I = Initial
\+ = If available

Table 20. Space Allocation for Identifying Information - Number of Columns

	RPB	*DEATH REG**	*SIN INDEX**	*MDB***	*NCIRS***	*PRO POSE*
Surname	12	17	20	10	21	2
Former Surname(s) if any	12		20		10	2
First Given Name	9	9	13	9	16	
Second/Other Given Names	7	7	12	7		
Usual Name or Nickname						7
Sex	1					7
Birthdate	6	5	7	7	1	1
Birth Province or Country	2	2		2	8	8
Birth City/Place					4	2
Father's Surname				10		5
Father's Given Names	9			2***		12
Mother's Surname	12	10	20	10		20

* = Reference 4
** = Reference 6
*** = Initials